PROCEEDINGS

OF THE

AMERICAN ACADEMY

OF

ARTS AND SCIENCES.

NEW SERIES.
VOL. VI.

WHOLE SERIES.
VOL. XIV.

FROM MAY, 1878, TO MAY, 1879.

SELECTED FROM THE RECORDS.

BOSTON:
PRESS OF JOHN WILSON AND SON.
1879.

CONTENTS.

PROCEEDINGS

OF THE

AMERICAN ACADEMY

OF

ARTS AND SCIENCES.

VOL. XIV.

PAPERS READ BEFORE THE ACADEMY.

I.

ON THE YOUNG STAGES OF BONY FISHES.

BY ALEXANDER AGASSIZ.

Presented May 28, 1878.

II. *Development of the Flounders.*

A YOUNG Flounder, immediately after its escape from the egg, presents no special points of difference from the embryos of other bony fishes, in a similar stage of growth. There are, however, in the earlier stages also many points in common, to which but little attention has been paid, thus far; and the study of these characters presents, from an embryological point of view, many features of special and also of more general interest. As I have already treated of the development of the tail and head (in Part I. of these Studies),* the gradual passage from a leptocardial tail, such as we find in Pl. III. fig. 1, to a so-called homocercal tail (Pl. IV. fig. 5), I will not refer to this again, beyond calling attention to the peculiar physiognomy of these young bony fishes, while in the stages (Pl. III. figs. 3–5, and Pl. IV. fig. 1) during which the heterocercal tail is so prominent a feature, and before the fins characteristic of the osseous fishes have become wholly or partially differentiated from the primitive embryonic fin-fold, which extends from the base of the head, and runs more or less parallel with the dorsal chord, round the anal extremity, back toward the anterior

* Proceedings Am. Acad. Arts and Sciences, xiii. 117. Boston, 1877.

part to the anal opening. Their general resemblance, at this time, to the Ganoid types of older periods, and especially to the Amias of the present day, cannot be too strongly insisted upon. In the Flounders, there is usually but a single dorsal and anal fin, formed from the original embryonic fin-fold. I will only notice, in a general way, the separation of the anal and dorsal from the caudal, by the earlier appearance of the permanent fin-rays; and the more rapid growth of the caudal, during the time when, in the dorsal and anal fin, the embryonic fin-rays, which disappear with the growth of the permanent ones, are still the most prominent feature. Little by little, however, with the increase in depth of dorsal and anal (Pl. IV. figs. 2, 3, 4, 5), the separation between these and the base of the caudal becomes more abrupt; and this, accompanied by the gradual shrinking of the remnant of the embryonic fin-fold at the base of the caudal both above and below, soon brings the relations of the three principal fins of the Flounders to the proportions they bear in the adult (Pl. IV. fig. 5). In another species (Pl. IX.), I shall describe the gradual development of the anterior dorsal out of the primitive embryonic fin-fold. In the bony fishes, neither the development of the ventrals nor the pectorals has yet been traced from a lateral embryonic fin-fold; but, in sharks and skates, the case is different. (See J. Wyman,* in his development of Raja.)

We may perhaps find hereafter, in the development of such forms as Lumpus, Liparis, and the like, a nearer approach to the Selachian mode of development of the paired fin-rays. In those of the bony fishes the development of which I have had an opportunity of following, the pectorals are well developed; early assuming, even while in the egg, the Ganoid (Crossopterygian) type, to which I have already alluded in the first part of this paper.† In some of the earlier stages, the lateral embryonic fold, from which the pectorals are formed, can be distinctly traced, — though never assuming the great prominence which it has in the dorsal or anal embryonic folds, the paired fins early concealing the lateral folds; while it is the reverse with the dorsal and anal folds, from which the dorsal and anal fins are developed late.

The ventrals, on the contrary (Pl. VI. fig. 5, Pl. VII. fig. 4, Pl. IX. fig. 6), make their appearance very much later, and, in our Flounders, at

* WYMAN, JEFFRIES. Observations on the Development of Raja Batis, in Mem. Am. Acad. Boston, 1864. And also BALFOUR, F. M. Elasmobranch Fishes.

† AGASSIZ, ALEXANDER. On the Young Stages of Osseous Fishes. Proc. Am. Acad. xiii. Boston, 1877.

first as a mere swelling of the median line, behind the hyoid bone; this (Pl. IV. figs. 3–5) grows quite rapidly; the permanent fin-rays at once make their appearance, — the anterior ones (the outer) first; and there is nothing special to note in the further development of the ventrals, which soon resemble, on a small scale, the ventrals of the adult. The ventrals possess, at no time, embryonic fin-rays, like those of the dorsal, anal, and caudal fins, formed from the longitudinal embryonic fin-fold. In the pectorals, embryonic fin-rays also precede the formation of the permanent rays; but in many bony fishes (Pl. VI. fig. 5, Pl. X. fig. 1), these permanent rays appear very early, — before those of other paired or unpaired fins, — the Crossopterygian stage being passed while still in the egg.

A striking characteristic of the young of all bony fishes is the extraordinary development of the pigment cells (chromatophores and chromatoblasts), and the great changes they undergo during the growth of the embryo. Pouchet* has more recently called attention to the wide-spread existence of these pigment spots, so well known to all students of Invertebrates. He studied them especially among the Fishes, in connection with the atrophism of the color on the blind sides of Flounders; pointing most plainly to the partial atrophy of the great sympathetic nerve, effected during the passage of the eye from the right to the left, or *vice versa*, as the cause. The power of the nervous system over the complicated system of pigment spots, which produces eventually the coloring of the adult fish, is of course much more readily traced in the younger stages, while the individual cells are still isolated, and before their anastomoses have become so complicated that it is well-nigh impossible, even in quite young specimens, to follow the changes resulting from any special nervous excitement. Compare, for instance, the simple chromatic system of cells of Pl. II. figs. 1–4, with the more and more complex anastomosing branches of Pl. III. figs. 5 and Pl. IV. figs. 1–5. This is still better seen, perhaps, if we compare Pl. VI. figs. 1–3 (young Flounders, just hatched from the egg, and a couple of days old) with Pl. VI. figs. 5–7, showing the gradual passage of the few, large, well-individualized chromatic cells of Pl. VI. fig. 3, into the innumerable system of small cells, closely packed and crowded in spots, so as to form the special design characteristic of this species.†

---

* Pouchet, G. Des Changements de Coloration sous l'Influence des Nerfs. Archives de Physiologie et d'Anatomie. 1876.

† Pouchet has succeeded in producing a white side in trouts, by destroying the eye of that side. Rev. Scient. xiii. 1877.

The young Flounder has already attained a considerable size, before any signs appear of the change in the position of the eye on the left side (see Pl. III. figs. 3–5 and Pl. IV. fig. 1), and before the young fish shows the least tendency to favor one side over the other. Not until the young fish is fully three-eighths of an inch in length can the first slight difference be perceived in the position of the two eyes (when seen from above), the left eye being somewhat in advance of the other. In this species, the Flounder eventually lies down on the left side, which becomes colorless. In order to prevent repetitions, we shall call this the case of a right Flounder (dextral), — that is, of a Flounder colorless on the left side, and where the left eye has passed over to the right side, — calling the sides, at the same time, either blind or white, and the opposite ocular or colored.

Plates III. and IV. show very well the changes of form through which the young dextral Flounder passes before it finally assumes the appearance of the adult, and habitually rests with its colorless side upon the ground. All young Flounders, even long after they have all the characteristics of the adult, very frequently swim vertically for quite a length of time, or else swim near the surface, with the undulating movement they have when swimming over the bottom, their heads well raised, and bodies carried flat, parallel to the surface. Even quite old Flounders sometimes are caught swimming near the top of the water. Almost all the stages figured in Plates III. and IV. were caught near the surface, swimming vertically, like any other young bony fishes; but this they do only when they come up to feed, while the water is very smooth, about ten in the morning, on very bright sunny days, when they may be seen eagerly devouring swarms of embryo Crustaceans, of all orders. The young of other fishes seem to share this habit; for of the latter I have examined no less than twenty-five species, caught at various times with a hand-net, swimming near the surface of the water, on bright sunny days, when not a ripple ruffled the sea. With the least movement, all the more delicate of these embryos vanish; leaving only the older and more vigorous, which in their turn disappear, and seek shelter in deeper water. Only when the young fishes are old enough to be recognized as the young of their tribes, do they venture to join them in their ordinary haunts.

Pl. V. figs. 7–11, Pl. VI., and Pl. VII., on the other hand, give us in general the changes of form a young sinistral Flounder undergoes from the time it leaves the egg until it assumes the characteristics of the adult. The explanation of the plate will give all the necessary details of the changes, which are mere repetitions of those described

in Pls. III. and IV.; with the exception, of course, that the blind, colorless side is now found on the right side of the fish, the left side being the chromatic side. This species, as compared with the dextral species, is remarkable for the greater development of the pigment cells, figured on Pls. III. and IV. The young Flounder (Pl. VI. fig. 7), when not more than three-fourths inches long, is already quite opaque, the whole colored side being thickly covered with minute pigment cells: they extend also upon the dorsal and anal, in irregular blotches, forming only in later stages the patterns which characterize some of the species among our Flounders. It is not uncommon for a peculiar pattern to appear quite early (see Pls. VII. and IX.).

In the present species, the pigments of the dorsal and anal do not appear before the stage figured on Pl. VI. fig. 5.

As will be seen, on an examination of the figures of Pl. VI., the earlier stages (Figs. 1–5) are readily recognized by the total absence of pigment cells in the extremity of the caudal. This feature still persists, in quite well-advanced individuals (Pl. VI. figs. 6, 7, 8). The tail, in this species, passes rapidly through the heterocercal stages, and does not present the striking external resemblance to that of Ganoids, so characteristic of the species figured in Pls. III. and IV.

On Pl. V., additional details have been given of the mode of transfer of the eye from the one side to the other, — either the right eye to the left side, or *vice versa*, — which, with the figures of the embryos, on Pls. III., IV., VI., will show very clearly how the transfer is accomplished, in the ordinary case of a dextral or sinistral Flounder.

While still in the egg (Pl. V. fig. 6), and for some time after hatching (Pl. V. figs. 1, 2, 7, Pl. III., Pl. IV. fig. 1, Pl. VI. figs. 1–4), the eyes of the two sides are placed symmetrically on each side of the longitudinal axis. The first change — and the process is identical, whether we take a right or a left Flounder — is the slight advance towards the snout (Pl. V. fig. 3) of the eye about to be transferred; so that the transverse axis, passing through the pupil of the eyes, no longer makes a right angle with the longitudinal axis. This movement of translation is soon followed by a slight movement of rotation; so that, when the young fish is seen in profile, the eyes of the two sides no longer appear in the same plane, — that on the blind side being now slightly above and in advance of that on the colored side (Pl. IV. fig. 2, Pl. V. fig. 5, Pl. VI. fig. 5, Pl. IX. fig. 7). With increasing age, the eye on the blind side rises higher and higher towards the median longitudinal line of the head; a larger and larger part of this eye becoming visible from the colored side, where the

embryo is seen in profile (see Pl. IV. figs. 3–5, Pl. VI. figs. 6, 7, Pl. V. figs. 8–12, Pl. VII. fig. 5), until the eye of the blind side has, for all practical purposes, passed over to the colored side (Pl. V. figs. 4, 11).

The rapidity and extent of this translation and rotation of the eye from the blind to the colored side can be best seen on comparing the profiles of the heads (Pl. V. figs. 5, 10) of a dextral and a sinistral Flounder with the profiles seen from the colored sides, before the eyes have begun their movement (Pl. I., Pl. VI. fig. 6, Pl. VII. fig. 5).

As the dorsal, little by little, with advancing age, extends along the head towards the nostrils, it soon, in old specimens, finds its way behind the eye which has come from the blind side (compare the position of the anterior part of the dorsal, in Pl. VI. figs. 5 and 7, in Pl. IV. figs. 2 and 5, and Pl. VIII. fig. 3). This continued advance of the dorsal anteriorly, after the eye has passed to the colored side, naturally gave rise to a great many theories respecting the passage of the eye through the head, under the anterior part of the dorsal fin; and many naturalists, after an examination of the twisted facial part of the skull on the adult, have attempted most ingenious explanations of the mode by which the eye reached its ultimate position.

The facts contained in this paper leave no doubt that, at any rate, in the majority of the Flounders of our coast (I have traced the development of eight species), the transfer of the eye from the blind side to the color side occurs very early in life, while all the facial bones of the skull are still cartilaginous, and that long before their ossification the eye has been transferred, by a combined process of translation and rotation, to the colored side. Let x, y, z be rectangular axes; and, if we call the longitudinal axis of the body twisting x, the transverse axis at the extremity of which the eyes are placed in the plane xy, the first change taking place is that x is no longer at right angles with y, though the eyes are still in plane xy. The next change is that the plane in which the eyes are now placed ($x'y'$) makes an angle with the xy; cutting z at a slight distance above the origin of the coordinate axes, the eye of the colored side forming the apex of the angle. This angle gradually increases, until it passes beyond the plane yz, when the eye from the blind side has reached the colored side.

The subsequent modifications of the frontal bone, owing to the aberrant position of the eye from the colorless side, are interesting on account of their connection with abnormal anatomical features found in the Flounders; but they explain in no wise the mode in which the transfer of the eyes has taken place, this being anterior to any essential changes in the frontal bone. In early life, the strong muscles which

control the motion of the eyeball in the young Flounder maintain also a very powerful strain upon the frontal bone while still cartilaginous and readily flexible, and no doubt help to twist it in accordance with the gradual change in the position of the eyes.

While the observations of Malm on the young stages of Flounders tended to show the improbability of the eye passing through the skull from the blind side to the binocular, the observations of Steenstrup on the genus Plagusia, seemed, for that genus, at any rate, to show clearly that the eye did pass through the tissues of the head, during its transfer from the blind to the binocular side. But neither Malm nor Steenstrup, nor subsequently Schiödte, actually traced the changes undergone during the process. Steenstrup's specimens were alcoholic; and, although his theory was substantiated by observations on a number of intermediate stages of the passage of the eye through the tissue, yet, on the other hand, the observations of Malm, making it probable that the eye merely went round the head, in a manner not yet explained, were equally precise. I had myself traced quite a number of Flounders, in all of which the eye was transferred in accordance with the process described in the commencement of this paper, and figured on Pls. III.–VIII., — a process completely in accordance with the suppositions of Malm, and in direct contradiction to the theory of Steenstrup. In the late summer of 1875, however, I traced to my satisfaction the development of a very transparent Flounder (Pl. X. fig. 1), — so transparent, indeed, as to rival the most watery of Jelly Fishes. When placed in a flat glass dish, it could only be distinguished by allowing the light to strike it in certain directions: otherwise, all that was visible were the two apparently disembodied bright emerald eyes, moving more or less actively.

In this Flounder (Pl. X. fig. 1), already of a considerable size, — over an inch in length, — the position of the eyes was perfectly symmetrical. They were placed also at considerable distance from the anterior extremity of the snout; so that, judging from the size of the fish and the position of the eyes, as well as from the extension of the dorsal almost to the nostrils, I inferred that I had a new Flounder, in which the eyes would probably always remain more or less symmetrical, and in which the transfer of the eye from one side to the other was replaced by the exceeding transparency of the body, allowing either eye, owing to the great range of motion of the eyes both in a vertical and horizontal direction, — a feature characteristic of all Flounders, — to be really useful on both sides of the body. A Flounder can move his pupil vertically and horizontally through an

angle of at least one hundred and eighty degrees. Thus, our transparent Flounder, which I did not at first recognize as the Plagusia of Steenstrup, could readily, by looking obliquely, see with great distinctness, through the transparent tissues, what was passing on the opposite side of the body.

I made all preparations to watch the changes in this interesting fish, should any such take place; and, a couple of days afterwards, I noticed the first change in the position of the eye (Pl. X. fig. 3) of the right side. No less than fifteen of these transparent Flounders were caught at the surface, with the hand-net, at the mouth of the harbor of Newport, close to the shore, on a very quiet and brilliant morning. They were then swimming vertically, and rushing violently after the minute Entomostraca swarming on the surface; but, as soon as they were confined in shallow glass jars, they turned on the right side, where they would often remain immovable on the bottom for hours. They were rapid in their movements when disturbed; frequently jumping out of the water and over the sides of the dishes, to a considerable distance. Though they appear so delicate, they do not seem to suffer, any more than other Flounders, from their momentary stay on dry land. When swimming vertically, they usually move obliquely, the tail kept much lower than the head; and, when seen endways, are more or less curved, owing to the extreme tenuity of their body (Pl. X. fig. 2).

During the change of the eye from the blind to the binocular side of the body, the outline of the young fish becomes more rounded anteriorly; and the minute, dotlike yellow and black pigment spots, hardly perceptible in Fig. 1, Pl. X., form somewhat more prominent patches on the sides of the body, and radiating lines parallel to the fin-rays on the dorsal and anal fins (Pl. X. fig. 11).

The right eye (Pl. X. fig. 3) could, when the fish was in profile, be seen through the head slightly in advance, and somewhat above the left eye; the right eye in that position, owing to the great transparency of the body, being quite as useful as if it had been placed on the left side. In the following stages, the right eye rises gradually more and more above the left eye, in a somewhat oblique direction towards the fifth or sixth anterior ray of the dorsal, until the fifth or sixth day, when the right eye can be seen entirely clear of the left eye, well above it (Pl. X. fig. 4). Owing to the great size of the orbit, the left eye, when seen from the left side (Pl. X. fig. 3), sometimes appears shot a little behind the right, especially after the motion of rotation has commenced; for we find that in this Flounder, as well as in the others, the transfer of the

eye from the right side to the left takes place by means of a movement of translation, accompanied and supplemented by a movement of rotation over the frontal bone. But, in this case, very special conditions attend the transfer, which, at first sight, seem to make the passage of the eyes of this species an exceptional one. I think we can easily show that the present mode of transfer does not differ so radically as would at first seem from the conditions described in the other species, in the beginning of this paper. When the right eye of the young Flounder has reached the frontal bone, and approaches the base of the dorsal, we find, on turning the fish on his left side, that the right eye is no longer on the outer surface of the right side. It no longer occupies, as in the earliest stages, a huge orbit, capable of extensive movements in all directions; but unlike the left eye, which has retained all its former powers of locomotion, as well as its original place, it has gradually sunk deep into the tissues of the base of the dorsal fin, between it and the frontal, — having sunk, indeed, to such an extent that the huge orbit, so characteristic of all Flounders, has gradually become reduced to a mere circular opening. Through this opening, the eye now communicates with the exterior; while, from its position above the frontal (Pl. X. fig. 4), it has, when the pupil turns to the opposite direction, a perfectly unobstructed vision through the transparent left side of the body. Little by little, the opening on the right becomes smaller and smaller; and as, at the same time, the eye pushes its way deeper into the tissues, an additional opening is now formed on the left side (Pl. X. fig. 7), through which the right eye can now communicate directly with the left exterior on the left side of the body. Thus, in the stage intermediate between Pl. X. fig. 4 and Pl. X. fig. 8, we find no less than three orbital openings: one large one, — the original one of the left eye; a smaller one, on the left side also, the new orbit formed for the right eye, as it has pushed its way through the tissues of the base of the dorsal fin; and a small orbit on the right side, the remnant of the original right orbit of the right eye, which, before the right eye has completely passed over to the left side, becomes entirely closed (Pl. X. fig. 8). With the continued sinking of the right eye, the gradual resorption of the tissues, and the closing up of the old orbit, as the eye works its way across the head, we eventually get the right eye entirely over to the left side. It has now, by a movement of translation and of rotation, penetrated through the tissues between the base of the dorsal fin and the frontal bone; having apparently passed through the head, as was suggested to Steenstrup, by his examination of the alcoholic speci-

mens which furnished him the materials for his paper on Plagusia. The present transparent species evidently belonged to this genus (Plagusia); and I had thus succeeded in actually tracing, in one and the same individual, the passage of the right eye to the left side through the head.

If we now compare this method of transfer of the eye through the head with the transfer previously described round the frontal bone on the exterior of the head, we can readily see that the difference is not as great as it would appear at first sight. Were we to imagine this species of Plagusia with a dorsal, stopping in the anterior median line behind the posterior edge of the eyes, the transfer would then take place exactly as in the case of the common Flounders. The right eye would travel round the frontal, without having to sink into the tissues; and, if subsequently to the transfer of the right eye to the binocular side, the anterior portion of the dorsal were to extend in advance of the anterior edge of the eyes to the intermaxillary, we should then obtain a result identical with that described before, and one which actually occurs in precisely this manner as we have seen in a number of Flounders; and the mere resorption of the tissues at the base of the anterior part of the dorsal, while interesting as a short-cut to an end, is not of so great physiological value, or so important as a difference in the method of the transfer of the eye, as appears on a first examination.

Owing to the transparency of this Plagusia, several interesting structural details could readily be followed, which only tedious manipulation would have demonstrated in the other more opaque species, of which the development is here given. Among these were the great length of the optic nerve, which allows, as it were, sufficient slack to be taken in during the transfer of the eye from the right to the left side (Pl. X. figs. 4, 8, 9), so as apparently not to interfere in any way with the sight of the right eye; also, the immense accumulation of muscular bands forming the sheath of the orbits of the eyes, and providing for the great variety and range in the movements of the eyeball and lids (Pl. X. figs. 3, 4, 5, 8, 9); also the direct and very active circulation taking place to and from the heart with the cavity of the orbit of the eyes. (See Pl. X. fig. 9, where the direction of the arrows shows the course of this current.) The presence of this circulation of a so-called ocular heart can be readily traced in the adult of our Halibut.

The Flounders have thus far only been found in the most recent geological deposits: they seem to belong peculiarly to the present period. It is certainly remarkable that no Flounders should have

been discovered among the true bony fishes, which date back as far as the Jurassic Period. To whatever cause we may ascribe the peculiar development of the Flounders, it seems to have been inactive during the periods immediately preceding our own; and, in the absence of any plausible explanation of their appearance and development during the present period, we must look to some exceedingly subtle agency, of which we have at present no conception. The causes usually assigned for the development of fishes with a binocular side are all unsatisfactory; and all are invalidated by the fact that similar conditions constantly fail to produce like results. The Flounders are usually said, for instance, to rest on one side, because the great width of the body makes it the most natural position; but there are many other fishes of far greater width which always swim vertically, and never show any tendency to assume the pleuronect mode of locomotion. In fact, the great development of the dorsal and ventral fins gives to Flounders special advantages over other fishes for maintaining a vertical position. The young Flounder also shows a tendency thus to rest on one side, at a time when the young fish is much like any other fish, long before the habit could be of any special benefit or use.

The absence of a swimming-bladder has also been assigned as a principal cause of the peculiar mode of locomotion among Flounders. But there is one of our Flounders in which a swimming-bladder is already well developed in the young fish; and this does not prevent that particular species from adopting, as early as the others, the Flounder mode of locomotion.

The only other cause we can assign is that broad fishes, like the Flounders, find it of course much easier to pursue their prey, if, while swimming close to the bottom, they are protected from detection by a complicated system of pigment cells, for producing colors or patterns within certain limits, so as to resemble sand, mud, or gravel. This would gradually lead to the exclusive use of one side (should the fish lie on either side), and would result in the atrophy of the eye, unless the fish were able to transfer his eye to the other side, and thus retain it; when, as a secondary cause from this, the atrophy of the pigment cells of one side would follow. If this, however, is the natural explanation, why do not we find Flounders in almost all families of fishes, — at least, among the broad forms of the group, — and why were they not as common in earlier times as at the present day? We have also to face a very interesting point of heredity. It would certainly seem far simpler for the Flounders to hand down, from generation to generation, the two eyes on one side of the body, and

further to hatch their young, as other fishes do, with the characters of the adult; instead of leaving for a future period (and a period of great mortality among them) the development of the transfer of the eyes to the right or left, — thus transmitting merely the tendency, and not the thing itself, as we find to be the case in Acalephs (Hybocodon), in the Tunicates, Salpæ, in the Gasteropods, in the Polyzoa, &c. Yet this tendency is very well defined; for we rarely meet with dextral forms when the Flounder is sinistral, or *vice versa;* and I have, in our common Flounders, met with no instances of reversal in the course of the development. In Plagusia only did I notice such a reversal, where there was an attempt made in many cases — seven out of fifteen cases — by the young fish to force the left eye to pass to the right side by lying down on the left, but in no case did this prove successful; and, after a while, the young fish showed traces of brain disease, and soon died, usually before the process of transfer of the eye had made much progress, — showing that a violation of the normal mode of transfer cannot readily be made with impunity. This may be the explanation of the rarity of such abnormal cases in the whole family.

The attempts which I made, both in Plagusia and several of the other species of Flounders, to prevent the transfer of the eye by placing the glass dish at a height over a table, and thus allowing the light to come from below, as well as from all other sides, failed in arresting the transfer. This experiment, likewise, produced no effect in retaining the pigment spots of the blind side longer than in specimens struck by the light only normally, from above.

The habits of young Flounders differ greatly from those of the adult: while the latter are generally more or less sluggish, the young Flounders, when measuring less than a couple of inches in length, are remarkably active, bounding through the water, as it were, and, if disturbed, frequently jumping out of the flat dishes in which I kept them. When this happened, falling from the table to the floor, they often remained a considerable time out of water, without appearing to suffer from their exposure, on being put back into water.

Giard has, in the Rev. des Scienc. Nat. for September, 1877, suggested that the fundamental cause of asymmetry in the animal kingdom was due to a difference in the strength of the organs of sense; and he has given, in support of this view, some most ingenious speculations on the asymmetry of Ascidians, of which the Tadpole was transparent, while opaque Tadpoles belonged to symmetrical types; the position of asymmetrical Ascidians being determined by

that of the organs of sense of the embryos. We might add here, in favor of this view, the asymmetricals of many Acalephs (Hybocodon), in which the disproportion of one of the organs of sense (tentacles) is very great. He further calls attention to the facts that, in Pteropods, it is the organs of sense which first show asymmetry, and suggests that cyclopism has been an indirect cause of restoration of symmetry; though this point does not seem well taken,—judging, at least, by what we know of the development of cyclopism among Crustacea. At any rate, the action of light upon organs of sense, which in all embryos are developed out of all proportion to their ultimate conditions, must remain an all-important element in its effect upon the nervous system. In embryos so transparent as many young fishes, which seem to be nothing but eyes, brain, and notochord, the action of light must be infinitely more potent upon the nervous system than it can possibly be in older stages, when the muscular system has obtained a so much greater preponderance. The sensitiveness of young fishes to the slightest disturbance of the water, either as a shock or from light, is exceedingly acute; while, when older, they are apparently insensible to the same causes.

I have nothing to add to the explanation of the mechanism of coloration given by Pouchet in his admirable memoir on the change of coloration, to which I have already referred. A recapitulation of the important points may, however, help the reader not familiar with his memoir to understand the changes taking place during the development of our young Flounders. In the coloration of fishes, we must distingnish colors due to interference of light produced by the presence of thin plates, and those due to anatomical elements frequently highly colored, and endowed with sarcodic movements capable of marked changes of form, under special influences, so as to present the shape of extended dendritic surfaces or minute spherical masses through which the pigment is distributed. The changes of coloration due to thin plates are, of course, exceedingly variable, the tints following each other with great rapidity, according to the angle at which we view them. Such lamellar coloration is common among insects, crustacea, and also in some families of fishes. Among the most beautiful examples are those of the dolphin (*Coryphæna*) and of Saphirina; while the second class of colors—those due to the movements of the anatomical elements—are directly connected with the impressions of color received by the eye, and brought about by the reflex action of the nervous system. That this is the case, the rapid change of coloration produced by placing Flounders upon differently colored bottoms sufficiently proves. This

has, of course, a direct bearing upon the question of mimicry; but it must be frankly stated that, as far as the causes of coloration among animals have been studied, it is difficult to see how natural selection can have been a factor in producing permanent mimicry; while the rapidity with which many fishes adapt themselves to the color of the bottom upon which they live enables them undoubtedly to produce a protective coloration, which is of advantage to them; and constant habit may develop unequally the capacity of producing certain tints, or patterns even, which in their turn may be transmitted, and thus readily account for the lighter coloring of Flounders living upon sandy bottoms, as compared with those living upon rocky bottoms covered with dark algæ. Yet place the latter upon a light ground and the former upon a dark ground, and they will very soon adopt the proper coloration of their bottom, showing they have not lost their power of changing. As for many of the patterns of coloration of birds and in insects, produced by physical causes, it seems quite impossible to look upon them as the fortuitous product of the action of light, or to regard it as an efficient cause of protective mimicry.

The pigment cells appear early in the egg. In some of the fishes, we have even two color elements in the older stages, immediately before the young fish is hatched, — viz., the black and yellow; but, in the majority of cases, the black alone is present, the yellow element appearing subsequently, and, last of all, the red. The experiments made by Pouchet on pigment elements show that the blue pigments are probably only a dimorphic condition of the red pigments. This would give a ready explanation why Lobsters turn red when cooked, and of the blue Lobsters which are occasionally caught. The same may also be said of green. Violet pigment, which is found in some Crustacea, gives special reactions.

The anatomical elements containing the pigment are greatly changed during growth. The examination of the pigment spots of the youngest fish on any of the Plates here given with more advanced stages shows how great is the capacity for expansion in the black pigment elements, which from mere dots have almost become special organs capable of great expansion and contraction. Pouchet calls the pigment elements chromatoblasts in their embryonic condition, to distinguish them from the chromatophores into which they eventually develop. In addition to the chromatoblasts and chromatophores, Pouchet has also called attention to a third set of bodies, which he calls iridocytes. These are found in Fishes, Reptiles, Mollusks: they are situated near the surface of the integument, and produce the phenomena of iridescence

of cœrulescence by interference of light (as shown by Brücke), of solid particles more or less analogous to excessively thin laminæ. By simple combinations of the action of the red, yellow, and black chromatophores with the iridocytes are obtained all the colors which we can produce in Fishes, Reptiles, Crustacea, Mollusks, &c.; these colors resulting mainly from the expansion near the surface, or retraction into an inferior layer of the black chromatophore, which, thus mixed with the yellow and red, or with the iridocytes, at greater or less depths, suffice to produce all the variations of coloring of our young Flounders. An examination of Plate VIII., showing the changes of coloring produced upon young Flounders when placed upon differently colored bottoms, will readily show the process by which the different colorations are produced.

In the Flounders, after the eyes have passed to one side, the connection between the impression produced on the retina and the blind side becomes less and less distinct, until eventually a complete paralysis of the nerves affecting the chromatophores takes place; and little by little the blind side thus becomes white with advancing age.

The pigment cells are of three colors, — black, yellow, and red (Pl. VIII. fig. 6): the black expand nearest the surface, the yellow and red varying greatly in their position, according to the species. The black cells are all more or less dendritic when expanded, concentrating to a mere dot when wholly contracted. The proper mixture of the three colors in various degrees of expansion or contraction, combined with the suitable pattern of position, enables the Flounders to imitate so admirably the general effect of the ground upon which they are accustomed to feed, be it either sandy, gravelly, or muddy. So true is this, that often only a most practised eye could detect them, as, with the head slightly raised, the eyes starting out of their sockets far above the surface of the head, they turn actively in all directions, seeking for prey, or trying to escape the notice of their enemies. The rapidity with which they produce this change of color is quite striking; and, although it was well known that many fishes had the power to change gradually the tint of the body, it had not been noticed that it could be effected rapidly, and apparently at will, before it was recognized by Pouchet. I have not unfrequently removed the jar containing a young Flounder (Pl. VIII. fig. 2) from a surface imitating a sandy bottom to one of a dark chocolate color, and in less than ten minutes I have seen the black pigments obtain such a preponderance (Pl. VIII. fig. 1) that it would hardly have been possible to recognize in the dark, almost black fish the young Flounder, whose yellowish-gray speckled

hue had so well simulated sand, a few moments before. On removing him to a gravelly bottom, the spots of the side quickly became prominent (Pl. VIII. fig. 3). During all this time, the pigments of the blind side showed no trace of any sensitiveness; while, if these experiments are made when the eyes are still on both sides, the pigments of the two sides change at the same time in a corresponding manner.

It is well known that Squids and Cuttle Fish, provided as they are with exceedingly sensitive chromatic cells, are also able to imitate, for their protection and disguise, the coloring of the ground upon which they happen to live. But, in Cephalopods, the change of color of these chromatophores is more intimately connected with the nervous system, and appears far more sensitive and less subject to control than among fishes. In Cephalopods, the mere act of moving the mantle, of breathing, or of forcing the water through the siphon, seems sufficient to produce a change of tint; and a sudden disturbance is as likely to bring about a detrimental as a beneficial change of color.*

Among Fishes, Reptiles, and other Vertebrates, as well as among Cephalopods, and the mass of Mollusks, Crustacea, Annellids, Echinoderms, &c., in which we find dermal pigment cells, we can readily imagine how the effect of environments might, by reflex action, bring about a resemblance to surrounding coloring, as has been described by Pouchet and by Bert, thus producing general effects in the pigment cells, which would assimilate within certain limits with the surrounding tone. In all these cases, the explanation based upon mimicry as beneficial presents little difficulty; and we might suppose that by the laws of heredity those colors alone which had been stimulated by continued action through many generations would be transmitted. Thus Flounders, for instance, living on sandy bottom, in which the grayish tint imitating sand had been most constantly produced by the action of the proper pig-

* See the papers on the chromatophores of Cephalopods, by Hubrecht, Niederland. Archiv f. Zool., II. No. 3, p. 8, Mai, 1875, in which he makes a most interesting comparison of the phenomena of chromatophores and protoplasmic action. Also an important paper by Dr. Hagen, in the American Naturalist, vol. vi., July, 1872, on mimicry in the color of insects. The general results of Dr. Hagen's study of the phenomena of color in insects agree, in the main, with the results obtained by Pouchet from the study of Fishes, Crustacea, and Mollusks; both Pouchet and Hagen recognizing the presence of colors due to action of light, and the presence of colors due to pigments, the hypodermal and dermal layers. Judging from the interesting discussions brought out by the papers of Weismann, of Wallace, and others, on the causes of color in the animal kingdom, we are, however, only on the threshold of a most interesting and novel field of inquiry.

ment cells, would naturally transmit to their progeny in the greatest quantity only such pigment as would most easily reproduce the imitation of sand, while the same might be true of the Flounders living on muddy or gravelly bottoms. Something analogous exists in the common Echini, where dark-green and violet pigment spots closely imitate dark granitic rocks covered with seaweeds; or in the imitation of sand by the grayish-green tint of Mellita and the yellow tint of Amphidetus, &c.: yet the whole theory of mimicry, even in these cases, as a means of protection, is again overthrown by the mass of Clypeastroids, Spatangoids, Echinoids, whose dark coloring, but for their habit of burrowing in the sand in which they live, would make them most prominent objects. We next have the legions of Ctenophoræ, Jelly Fishes, and of other pelagic animals (especially the embryos) so transparent as to be scarcely distinguishable from the water in which they live, many of them are reduced to the merest film. Have they all, little by little, assumed their transparency, in order to escape their enemies? Then why do they swarm in such quantities that their numbers counteract the very object of their transparency? It is common along the seashore, at proper times of tide and wind, to find long lines where all these delicate and transparent animals are accumulated on purpose as it were to provide the food needed by their enemies, who are at hand playing sad havoc among them. Many of the embryos of our common marine animals are gregarious for a short period of their life; for instance, the young of the majority of our Crabs and Shrimps, of many Gasteropods, Annellids, and Radiates, just at the time when they are most delicate, and least capable of escaping the attacks of their enemies. At the time of hatching of the young Prawns (*Palæmonetes vulgaris*), and of the young of our Cancer, sea perch may be seen devouring them by the wholesale while they are swarming close to the shore. Thus, numberless young are destroyed in spite of their transparency, and the same holds good for a host of other embryos.

In the Flounders, we seem to have fair evidence that they are able to produce certain effects in consequence of impressions received upon the retina, and that the changes taking place on the chromatic side of the body are probably due to the capacity of the fish to distinguish certain colors from others. But more accurate experiments than I have yet made are necessary to enable us to decide whether the sense of color is developed so early in the Vertebrate series, or whether we have simply a set of reflex actions. It certainly seems, from a physiological point of view, very hazardous to infer — as has been frequently done on philological grounds — the gradual development of the sense of

color in early races of mankind, from the color descriptions of Homer and early Greek writers. It is not an uncommon thing to find children of the lower classes unable to give specific names to the different colors; but, if I am not mistaken, they can always distinguish the primary colors without difficulty, though not able to name them. Certainly, the facility for painting and coloring noticeable in the pottery of the uncivilized races of the world seems unfavorable to this theory.

EXPLANATION OF THE PLATES.

The Plates accompanying this paper are a fair sample of the results to be obtained from the transfer of original drawings by the Heliotype process. The drawings are quite acceptable reproductions of the originals; and this method of illustrating papers on Natural History will prove very useful in many cases. The method described by the younger Sars for obtaining transfers from original drawings is somewhat cumbersome, requiring a great deal of care and a number of processes. The present method simply requires for the naturalist that he should put on thin Bristol board the plate he desires to have transferred, of the size he wishes, and arranged as he desires; the only requisite being that the figures be all drawn with a pen and with a special ink. He may then be assured that he will get a plate nearly as clear as his original; and several transfers being made from the original,—say three or four,—a large number of clear copies can be struck off without reducing the distinction of the impressions, as is invariably the case in all lithographic processes. The delay incident to all lithographic processes requiring a special artist are done away with, and the author has only himself to blame for errors. This method seems to give better results than that employed by Sars. Compare his plates of Brisinga with those of the present paper. The cost of the Heliotype method is moderate; the impression on paper, and whole manipulation, after the drawing is supplied to the patentees of the process, being considerably less than the cost of printing and paper from an ordinary lithographic stone.

Plates III., IV., V., figs. 1–5, illustrate the development of a dextral Flounder, in which the eye passes from the left side to the right side.

Plate V., figs. 6–13, Plate VI., illustrate the development of a sinistral Flounder, in which the eye passes from the right side to the left.

Plate VII. illustrates the development of a sinistral Flounder, in which the eye passes from the right to the left side long before the dorsal, anal, or caudal fins have lost their embryonic character.

Plate VIII. illustrates the changes of color produced in the young Flounders by placing them on differently colored ground.

Plate IX. shows the development of a sinistral Flounder, in which the anterior part of the dorsal becomes to some extent an anterior dorsal.

Plate X. illustrates the passage of the eye through the integuments between the base of the anterior part of the dorsal and the frontal bone.

PLATE III.

PLEURONECTES AMERICANUS WALB.

Platessa plana Storer Pl. XXX. fig. 2.

Fig. 1. Young, about 4^{mm} long a few days after hatching. Seen from the left side. The eyes are symmetrically placed at the extremities of an axis at right angles to the longitudinal axis. The pectorals are well developed, the embryonic fin extends unbroken from the base of the brain to the anus, the ventral portion is somewhat broader. The eyes are of a light bright-green, and there are faint yellow patches on the lower sides of notochord along the muscular bands.

„ 2. Somewhat older than fig. 1. The tail has become slightly heterocercal, and the embryo is much less transparent than in the previous stage. The muscular tissue above and below the notochord is of a light-brown color, with yellow patches near the black pigment spots. One or two very indistinct tail-rays have begun to form.

„ 3. In this stage, the principal changes are confined to the increased number of tail fin-rays, and to the segmentation of the vertebral column sending out its dorsal and ventral cartilaginous apophyses. The pigment spots of the embryonic fin-fold (fig. 1), as well as of other parts of the body, seem to become more prominent, when increased activity in the formation of new tissues takes place. See the pigment spots in the tail of this figure.

„ 4. A somewhat more advanced stage, in which the dorsal and ventral embryonic fold has become tolerably separated from the tail-fin. At the base of the dorsal and ventral folds, the basal fin-rays are well developed, but as yet we find no trace of the fin-rays proper.

„ 5. In this stage, the tail-fin is in great part separated from the embryonic fin-fold, which shows here and there traces of the formation of the fin-rays proper; but in other respects it differs from the preceding stage mainly in the greater number of pigment spot patches, in the greater development of the muscular bands, and of the dorsal and ventral apophyses of the vertebral column. The eyes are as yet symmetrical. The length of this embryo is about that of the preceding stage (fig. 4).

PLATE IV.

PLEURONECTES AMERICANUS WALB.

Fig. 1. We now come to a series of stages in which the body becomes broader in proportion to the length, and in which the dorsal and anal fins are all gradually isolated from the caudal. In this stage, the fin-rays extend nearly to the edge of the dorsal and anal, the muscular bands are much wider, and there is a slight asymmetry in the position of the left eye, which has moved well forward towards the top of the snout; while in the preceding stages the left barely

extended to point of a vertical passing through the lower extremity of the upper jaw. The patches of color which are to be eventually characteristic of the species first make their appearance in this stage.

Fig. 2. Somewhat more advanced than fig. 1. The left eye, when seen from the right side, projects slightly in advance of the frontal. The dorsal and anal fin-rays are well developed, but still united to the caudal. The tail has become rounded. The patches of coloring are defined. Rudimentary ventral fins have appeared. There are as yet no hard rays in the pectorals.

" 3. In this stage, the left eye has moved more towards the crest of the snout, the dorsal and anal fins are disconnected from the caudal, and the ventrals are larger than in the preceding stage.

" 4. More than half the left eye is seen above the frontal ridge; the dorsal and anal still more disconnected from the caudal than in the preceding stage; the ventrals larger, and the pattern of coloration quite marked by prominent pigment cells.

" 5. In this stage, the left eye has fully passed to the right side, the dorsal fin, extending to the upper edge of the orbit, having gradually extended in that direction from stages represented in Pl. IV. figs. 2, 3, 4. The pattern of coloration of the body and of the fins is like that of the adult, but, of course, more indistinct. The dorsal and anal fins are now completely isolated from the caudal fin: they have both fin-rays fully developed, and have greatly increased in breadth since the last stages figured.

PLATE V.

Figs. 1–5. — Pleuronectes Americanus Walb.

Fig. 1. Head of a young specimen, about in condition of Pl. III. fig. 1. Seen from above, to show the symmetrical portion of the eyes.

" 2. Head of another specimen, about in the same stage as in fig. 1. Seen from below.

" 3. Head of a young specimen somewhat more advanced, in which the left eye has changed its position somewhat, and has advanced towards the snout; showing the effect, when seen from above, of the first movement of translation of the eye of the left side.

" 4. Head of young Flounder, intermediate between figs. 4 and 5, Pl. III., to show the transfer of the left eye above the ridge of the frontal bone.

" 5. The head of a young Flounder, nearly in the same condition as fig. 4. Seen from the left side, showing the position of the eye during the transfer while projecting above the frontal bone.

Figs. 6–13. — Pseudorhombus maculatus Stein.

Fig. 6. Head of young specimen still in the egg. Seen from above. The eyes symmetrically placed at extremity of a transverse axis at right angles to the longitudinal axis of the Flounder.

Fig. 7. Head of same species, a couple of days after hatching, before any movement of translation or of rotation of either eye has commenced. The two eyes symmetrically placed at the extremities of a transverse axis at right angles to the longitudinal axis of the Flounder.

„ 8. Shows the position of the eyes of the young Flounder from the left side, where the right eye projects beyond the ridge of the frontal bone.

„ 9. Shows the position of the right eye, seen from the right side, at about the time the lower edge of the orbit has reached the summit of the edge of the frontal bone.

„ 10-13. Show in regular succession the gradual passage of the eye from the stage of fig. 9 until it has reached, in fig. 13, the position it retains on the adult entirely on the left side of the body; the space between the eyes separated by the frontal ridge becoming less in each specimen with advancing age.

PLATE VI.

PSEUDORHOMBUS MELANOGASTER STEIN. MASS. FISH REP. 1872, p. 47.

Platessa oblonga Storer Pl. XXXI. fig. 2.

Fig. 1. Young specimen, just hatched from the egg. The yolk mass projecting below the outline of the lower surface; the dorsal embryonic fold much wider than the anal embryonic fin; the pigment spots are confined to the dorsal edge of the brain, and to the muscular band above the notochord.

„ 2. Embryo two days old. The yolk mass projects but little beyond the line of the lower surface. Large prominent pigment spots extend over the whole body, with the exception of a small portion of the tail, which is left bare from the earliest stages (fig. 1), and remains bare for some time yet, thus giving an excellent specific distinction for readily distinguishing the young of this species from other species of embryos about in the same stages. The snout has become more pointed than in the preceding stage, the dorsal embryonic fold has lost much of its width, and in consequence the young fish resembles a tadpole much less than in the preceding stage.

„ 3. Represents the same embryo on the fifth day after hatching. The principal changes consist in the form of the head, the prolongation of the lower jaw well in advance of the upper one, the presence of large pectorals, the increase of the stomach, and a very slight tendency to heterocercality in the tail.

„ 4. Somewhat older embryo. The stomach and alimentary canal have greatly increased in size, the air-bladder has become prominent, the body has greatly increased in width, the tail is decidedly more heterocercal than in the previous stage figured, and the right eye shows a slight tendency to move upward and forward towards the anterior edge of the snout.

Fig. 5. In this stage, considerably larger than the previous one, the change in the outline of the young fish is considerable. The dorsal is highest at its anterior extremity, the caudal is well separated from the dorsal and anal fins, in all the fin-rays are fully formed, the profile of the head is more blunt, and the whole body thickly covered with dark pigment cells.

„ 6. The differences of this stage from the younger one (fig. 5) consist mainly in the greater width of anterior part of the body; the distinct pattern of coloration; the increase in width of the dorsal and anal fins, and their disconnection from the caudal, which has become elongated and rounded at the extremity; the presence of small ventrals; and the transfer of the right eye forward and upward, so that one half is visible above the frontal from the left side.

„ 7. Is a young Flounder, taken late in the season, but slightly larger than fig. 6, in which, however, the right eye has passed well over to the left side. The dorsal has extended towards the posterior edge of the right eye, its anterior edge projecting over the eye. The pattern of coloration is similar, in a general way, to that of the adult, and extends into the base of the broad dorsal and anal fins. The ventrals are larger than in fig. 1. The Flounder in this stage and the preceding stages (figs. 4, 5) habitually rests on the right side, but as yet none of these young fishes show any difference in the coloration of the right from the left; the former being still quite as brilliant as the latter in the oldest stage here figured (fig. 6).

PLATE VII.

Rhombus maculatus Mitch.

Pleuronectes maculatus Storer Pl. XXXI. fig. 4.

Fig. 1. Young specimen, with rudimentary air-bladder, few pigment spots, measuring 5^{mm} in length.

„ 2. Somewhat more advanced than fig. 1. The pigment spots greatly developed, but the embryonic dorsal and anal fins show scarcely any advance.

„ 3. The body has become somewhat broader, the tail far more heterocercal, and rudimentary fin-rays appear both in the dorsal and anal fins. Patches of coloring indicating the future pattern are well defined.

„ 4. Somewhat more advanced, but slightly longer, than fig. 3. The base of the fin-rays of the dorsal and anal are well developed. The body, with the exception of a bare space of the tail and adjoining part of the body, is of a uniform grayish-brown color, with patches of yellow, and black longitudinal lines along the upper and lower edges of the notochord, and the base of the dorsal and anal fin-rays, as well as following the muscular bands along the ventral edge. The upper and posterior edge of the stomach is covered by intensely black pigment spots closely crowded together.

Fig. 5. Slightly older than the preceding stage. The eye, from the right side, projects above the line of the snout; the coloring much as in fig. 4. The anal, dorsal, and caudal fins are, however, more advanced.

PLATE VIII.

Rhombus maculatus Mitch.

Fig. 1. Young sinistral Flounder, natural size, showing the color assumed when the fish is placed upon a dark mud-colored ground.
„ 2. The same fish, somewhat enlarged, showing the coloring assumed when placed upon a yellowish sandy soil.
„ 3. Another specimen of the same species, somewhat younger than the preceding stages, showing the coloring assumed when placed upon a mottled ground (partly gravel, partly sand) somewhat darker than the yellowish sandy soil.
„ 4. Black pigment spots forming the blotches along the lines of the rays of the dorsal, when fully expanded.
„ 5. Another portion of the dorsal, showing the spots when contracted.
„ 6. A portion of the pigment spots of the colored side, showing the red, the yellow, and the black pigment spots when fully expanded, the darker tints between the colored pigments representing the masses of iridocytes.

PLATE IX.

Pseudorhombus oblongus Stein.

Platessa quadrocellata Storer Pl. XXXI. fig. 3.

Fig. 1. Egg of Flounder, showing the symmetrical head of embryo.
„ 2. Head of young Flounder, the fourth day after hatching. Seen from above.
„ 3. Head of fig. 4. Seen from below.
„ 4. Young Flounder. Seen in profile. Quite transparent. Remarkable for the great development of the dorsal embryonic fin, 6.5^{mm} in length.
„ 5. Somewhat older than fig. 3. First trace of heterocercal tail.
„ 6. Older than fig. 4. The anterior part of the dorsal is developed before the rest, forming a sort of anterior dorsal. The eyes are still symmetrical.
„ 7. Young Flounder, quite well advanced. The fins are all differentiated. The right eye has, however, moved, thus far, but little forward and upward.

PLATE X.

Plagusia Sp.

Fig. 1. Young Plagusia, slightly over an inch long. Seen in profile. The eyes of the two sides are equally distant from the snout: they are placed symmetrically with reference to a longitudinal axis, and a plane

passing through the transverse axis. This specimen is perfectly transparent, — fully as transparent as the most delicate Hydroid Medusa. The action of the heart, the course of the vessels, can be readily followed, as well as the other structural details, which are usually only visible after dissection. The dorsal fin projects far down the frontal ridge to the nostrils, well in advance of the eyes.

Fig. 2. Young Plagusia (fig. 1). Seen with head on.

„ 3. Shows the relative position of the eyes after the first movements of translation and of rotation have become visible by the slight advance and rising of the eye of the right side. Seen from the left side.

„ 4. Somewhat more advanced than fig. 2. Seen from the right side. The outline of left eye can be traced through the tissues of the head.

„ 5. Head, seen from the left side. The right eye has moved upwards sufficiently to be seen through the tissues of the head, clear above the left eye. We find in this stage the first trace of the opening of the eye on the left. The eye, when turned in the socket, can look through the tissues at the base of the dorsal; and, when thus turned, to see through the left, is nearly as sensitive to approaching objects as the left eye. When looking at the same fish for the other side (the right), we find that the eye has deeply sunk in the tissues between the frontal bone and base of dorsal fin, and that, while sinking and pushing its way to the opposite side, the tissues of the right side have gradually united and narrowed the former large circular orbit to a mere small elliptical opening.

„ 6. The eye of the right side, as turned to the right; the new orbit appearing on the upper edge of the eyeball.

„ 7. The same eye with the ball turned toward the left, showing the commencement of the new orbit forming as a small circular opening on the left side of the fish. The old orbit of the right side being now reduced to a minimum, the fish now having two orbits on the left side and one on the right. The orbit of the right being reduced to a small aperture, and disappearing in a subsequent stage (fig. 9), while the new orbit of the right eye on the left side is as yet much smaller than the corresponding orbit of the left eye.

„ 8. Head seen from the right side, showing the small size of the old orbit of the right eye after it has forced its way partly across the head.

„ 9. The right eye has now passed entirely round the frontal bone, and is held in its hollow curve, and has at same time forced its way through the tissues so far that the original orbit of the right side has become closed, and the new orbit for the right eye on the left side has become nearly as large as the orbit of the left eye.

„ 10. In this stage, the eye from the right side is now completely transferred to the left, and no difference is apparent between the orbits. In this and all preceding stages, the great length of the two optic nerves is readily seen; and we thus understand the possibility of so extensive a movement of either eye without interfering with the visual function. The slack of the optic nerves being only taken in for the eye which happens to be transferred in any genus of Flounder.

There is in Flounders a most active circulation going directly from the heart to the orbits and back again: this is well shown in this figure by the direction of the arrows along the vessels leading towards the orbits and back again to the heart.

Fig. 11. Is a young Plagusia, after the transfer of the eye, nearly three inches long, showing even at this stage but a slight accumulation of pigment spots along the dorsal and anal fins parallel to the line of the spines. A few yellowish and black pigment spots have also accumulated on the left side, but the young fish has as yet lost but little of its transparency.

What eventually becomes of this species I am not able to say, and it is not improbable that this species is identical with that described by Steenstrup, and it may also be the young of the Plagusia found on the Atlantic coast of the Southern States.

II.

EXPERIMENTS UPON PIEZOMETERS USED IN HYDRAULIC INVESTIGATIONS.

By Hiram F. Mills, *Civil Engineer.*

Presented April 10, 1878.

In making experiments upon water flowing in pipes and in open conduits, it is most convenient to measure its pressure against the side of the pipe or conduit, and its depth in the conduit, by means of small tubes extending through the side, normal to its surface, and communicating with vertical columns of water, contained in glass tubes or in small reservoirs.

Such columns of water, used to measure pressure, are called piezometers.

The question has arisen: Do they indicate the actual pressure against the side of the pipe, of the water when in motion, or do they indicate the actual height of the surface of the moving water in the conduit?

M. Darcy, in his great work * on the movement of water in pipes, says (page 217): "Indeed, manometers do not indicate the entire head of a conduit at the points where they are adjusted, but this head diminished by a certain height, the diminution being due to the velocity of the fluid at the base of the piezometers: the water, by its cohesion, acts upon the manometric column, whose height it lowers."

Again, he says: "When one of the manometers was placed upon the cylindrical reservoir, where the velocity of the fluid was very slight relatively to that of the water in the pipe, we see that in like circumstances the *lowering by suction* of the manometer upon the reservoir should be less than the *lowering by suction* of the manometer upon the pipe. . . . There was then a rectification to be made, but I have not at this time the means of making it. In the experiments relative to open canals, with which I am now occupied, I shall seek to determine

* Recherches Expérimentales relatives au Mouvement de l'Eau dans les Tuyaux. Par Henry Darcy, Inspecteur-Général des Ponts et Chaussées. Paris, 1857.

the law followed by these lowerings, according to the diameter of the orifice in communication with a current, and according to the velocity of the latter."

In the published records of the experiments relative to open canals,* the results here anticipated are not included, and we are not informed of the later conclusions of this able engineer.

In the performance of my duties as engineer of the Essex Company, — a company controlling the water power of the Merrimack River at Lawrence, Mass., — it has become important to interpret with accuracy the indications of piezometers, and to determine the circumstances affecting their reliability. To this end, a long series of experiments has been made upon piezometers, having orifices of communication of varying size and form, and through a wide range of velocities. The results of these experiments are regarded as of importance to investigators in hydraulics, and are, through the liberality of the officers of the Essex Company, now presented for their use.

It is well known from the experiments of Venturi † that within a short distance from the entrance of a pipe — a distance limited by the influence of the contraction at the entrance — piezometers indicate a pressure varying with their position, and widely different from that which obtains after the section influenced by contraction is passed. These phenomena are readily explained without attributing any discrepancy between the pressure upon the sides of the pipe and the indications of the piezometer. It is now, however, only necessary to consider that portion of the pipe or conduit in which uniform motion is established; that is, a portion in which the particles of water move parallel with the sides of the pipe with a velocity neither increasing nor decreasing.

Uniform motion then existing, the prominent facts to be determined are whether the height of the piezometric column is lowered by the cohesion of the water acting at the base of the piezometer or not; and whether or not the height of the column of still water indicates with accuracy the height of the surface of the adjacent mass of moving water in an open conduit.

---

* Recherches Hydrauliques, entreprises par M. H. Darcy, Inspecteur-Général des Ponts et Chaussées: continuées par M. H. Bazin, Ingénieur des Ponts et Chaussées. Premiere Partie: Recherches Expérimentales sur l'Écoulement de l'Eau dans les Canaux découverts. Paris, 1865.

† Tracts on Hydraulics. Edited by Thomas Tredgold, C. E. II. Venturi's Experiments on the Motion of Fluids. Second Edition. London, 1836, page 136 *et seq.*

For determining these facts, the apparatus represented upon plates No. 1 and No. 2 was constructed. It consisted of a straight trough thirty feet long, of uniform section, one foot deep and three-tenths of a foot wide inside, receiving water at A from a chamber four feet wide. At a distance of six-tenths of a foot up stream from the entrance was a gate B, which, being opened, connected the chamber with a penstock four feet wide, six feet high, and two hundred feet long, bringing water from the Essex Company's south canal. The down-stream side of the chamber A was built up to the height required during the several experiments; and its upper edge used as the crest of a regulating waste weir, over which water continually flowed into the waste trough C, which conducted it outside of the measuring basin.

The experimenting trough discharged its water at D into the swinging conductors, supported by the pivot *a*, which conveyed it by the branch E directly down into the measuring basin G, or by the branch F into the river, as the partition *b* was raised above or lowered below the stream.

The measuring basin G, 15.93 ft. wide, and 36.55 ft. long, and about 8 ft. deep, built of timber and planks on a firm foundation, was buried in earth nearly to its full depth, except on the river side, which was held from being pressed outward by a strong truss; and except at the observer's house H, where the heights of water in the basin were observed.

The area of the measuring basin, within the range of filling during the experiments, which was between 4.5 ft. and 6.5 ft. above the bottom, was, deduction being made for all supporting timbers for the upper works, found to be 570 square feet.

The depths of water in the measuring basin were measured by means of a hook gauge in the box *c*, which was in free communication with different parts of the basin by three pipes, 0.083 ft. in diameter.

The hook gauge used is described and illustrated in "Lowell Hydraulic Experiments," * page 18.

Water was drawn from the measuring basin through the waste gate *d*.

The experimental trough was at first placed level, having firm bearings about ten feet apart. The upper end was connected with the chamber A with a lining of rubber, making a water-tight joint, which continued water-tight when the other end of trough was lowered

* Lowell Hydraulic Experiments. By James B. Francis, C. E., &c. Third Edition. New York: D. Van Nostrand. 1871.

through its successive steps to increase the velocity of the wator passing through it.

Starting four feet from the entrance, cross bars of wood 0.9 ft. long, 0.1 ft. wide, and 0.15 ft. deep, were screwed to the top of the trough at intervals of just 2.5 ft., the top of the trough being let up into them 0.05 ft.

The up-stream top edge of each cross bar was taken as a station, and these were numbered from 1 to 11, beginning with the up-stream cross bar.

Under the projecting ends of the cross bars were attached, to the outer surface of the two-inch planks which made the sides of the trough, tin boxes about 0.9 ft. lòng, 0.5 ft. wide, and 0.9 ft. high, having blocks of wood fastened within some of them, as shown upon the plates, to reduce the free surface area of water which they would contain. These boxes, serving as reservoirs, and called still-boxes, were put in communication with the interior of the trough by passages having orifices of various forms and dimensions, and being variously disposed, as expressed in the following table: —

Number of Station.	Side of Trough.	Form of Orifice.	Distance of centre up stream from Station.	Distance of centre above bottom of Trough.	Diameter or Dimensions of Orifice.	Angle of passage with inside of Trough.	Material bordering Orifice.
			Feet.	Feet.	Feet.		
2	West.	Circle.	0.045	0.333	0.043	48° up stream.	Brass.
2	East.	„	0.062	0.333	0.043	48° down stream.	„
3	West.	Circle.	0.057	0.421	0.052	90°	Iron.
3	East.	„	0.054	0.497	0.066	90°	„
4	West.	Circle.	0.059	0.249	0.010	90°	Wood.
4	„	„	„	0.422	0.083	90°	„
4	East.	„	0.058	0.249	0.042	90°	„
4	„	„	„	0.411	0.021	90°	„
5	West.	Rectangle.	0.052	0.505	0.084 wide. 0.337 high.	90°	Wood.
5	East.	„	0.052	0.500	0.021 wide. 0.336 high.	90°	„
6	West.	Circle.	0.054	0.333	0.021	30° up stream.	Brass.
6	East.	„	0.083	0.333	0.021	30° down stream.	„
7	West.	Ellipse.	0.050	0.417	0.030 long. 0.021 high.	45° up stream.	Wood.
7	East.	„	0.053	0.420	0.030 long. 0.021 high.	45° down stream.	„
8	West.	Circle.	0.052	0.255	0.021	90°	Wood.
	„	„	0.052	0.420	0.042	90°	„
8	East.	„	0.052	0.333	0.010	90°	„
		„	0.052	0.502	0.083	90°	„
9	West.	Square.	0.053	0.500	0.167	90°	Wood.
9	East.	Rectangle.	0.053	0.336	0.334 long. 0.083 high.	90°	„
10	West.	Ellipse.	0.053	0.334	0.042 long. 0.021 high.	30° down stream.	Brass.
10	East.	„	0.054	0.334	0.042 long. 0.021 high.	30° up stream.	„

The water flowed toward the north. Distances indicating position of orifices were measured when the trough was level.

The trough with its appurtenances being in place, the whole was covered with a house about eight feet wide and ten feet high, having windows at the top.

The comparative heights of the water surface in the stream and in the reservoirs adjacent were now to be determined. The first step was to measure the heights of three points at each station — one over the middle of the stream, and one over each of the still-boxes — above a surface of still water. This was done by the aid of three kinds of instruments. The first kind, by which any change in height of the water surface was noted, consisted of a plate of brass placed horizontally, through which projected vertically upward fifty-one steel needles in two rows. The first needle being finished with its point just 0.1 ft. above the bottom of the plate, and the fifty-first having its point 0.11 ft. above the same surface, the intermediate points being separated by equal spaces, were finished to be in the same inclined plane with the extremities; hence each point was 0.0002 ft. higher than the next lower.

Six other needles, rising above these in another row, indicated the position of the points reading two-thousandths.

The second kind of instrument consisted of a rod having a scale divided into hundredths of a foot, sliding along a short standard having a stationary vernier reading to thousandths, by which distances of two ten-thousandths of a foot could be readily distinguished. The rods were held in a vertical position by fitting into frames above each point of observation. They were terminated at the lower end by a long finely pointed needle, which was brought in contact with the water surface.

The third kind of instrument consisted of a vertical micrometer screw, piercing a horizontal iron plate which made a part of its nut, and whose under surface was kept level by a level bulb upon its upper surface. The screw was terminated below with a finely pointed needle, and above, near the head, was supplied with an index, whose position was read upon a circular scale made upon the top of the nut, in which one ten-thousandth of a foot was indicated by the space of about one one-hundredth of a foot.

After determining by these instruments the actual heights above a datum plane of all of the points where observations were to be taken, the same instruments were used upon the same points for determining the heights of the water surfaces, when water was flowing through the trough.

During experiments with mean velocities less than three feet per second, the trough was maintained in its level position, and the height of surface and velocity were regulated by screwing a steel plate to the lower end of the trough at the proper height, thus discharging the water over a weir. With greater velocities, the plate was removed, and the trough was more or less inclined.

During experiments, the measurement of the quantity of water flowing through the trough was continuous, interrupted only by drawing water from the measuring basin.

Generally there were as many as four observers, with their instruments, making simultaneous observations at as many stations, with assistants to record their reading.

Upon experimenting with velocities greater than three feet per second, the disturbance at the entrance was found to continue past Station No. 1, consequently all the observations at this station are omitted.

At stations numbered from two to ten inclusive, 5925 observations were made upon the height of the different water surfaces, with velocities in the trough from about 0.6 ft. to about 9 ft. per second. These observations have been divided into 518 experiments, giving a series of heights in each still-box above the surface of the stream at the respective stations. These experiments have been grouped, by putting together those at each station in which the mean velocity and depth of water in the trough were nearly constant, and taking the mean of the heights of the water in each still-box above the surface of the stream. These mean results for each velocity, together with the depth of water, the number of observations, and number of experiments included in each result, are given in the following tables, and are followed by columns of corrected results, which are described in the headings:—

SUMMARY OF RESULTS AT STATIONS No. 2, No. 3, AND No. 4.

Mean velocity of water passing the Station.	Mean depth of water in the Trough.	Mean of observed heights of the surface of water in the still-boxes above the surface of the middle of the stream.		No. of Observat'ns.	No. of Experiments.	Mean of observed heights from which the third and fourth columns were obtained, corrected for the variation in height occurring in the interval of time between consecutive experiments.		Correction for slope of the surface of the stream between the point where height was observed and a point opposite the centre of orifice communicating with Still-box.		Corrected mean height of surface of water in the Still-box above the surface of the middle of the stream opposite the centre of orifice communicating with Still-box.		REMARKS.
		At the West Still-box.	At the East Still-box.			At the West Still-box.	At the East Still-box.	At the West Still-box.	At the East Still-box.	At the West Still-box.	At the East Still-box.	
RESULTS AT STATION NO. 2.												
Ft. per sec.	Feet.	Feet.	Feet.			Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	
0.64	0.7726	− 0.0024	+ 0.0032	60	4	− 0.0025	+ 0.0030	. . . . .	. . . . .	− 0.0025	+ 0.0030	
1.03	0.9163	− 0.0064	+ 0.0099	148	9	− 0.0062	+ 0.0101	− 0.0001	− 0.0001	− 0.0063	+ 0.0100	
1.74	0.7752	− 0.0200	+ 0.0226	108	7	− 0.0199	+ 0.0225	− 0.0002	− 0.0002	− 0.0201	+ 0.0223	
2.70	0.8899	− 0.0411	+ 0.0664	119	11	− 0.0410	+ 0.0667	− 0.0002	− 0.0003	− 0.0412	+ 0.0664	
5.23	0.6129	− 0.1880	+ 0.2489	56	5	− 0.1877	+ 0.2479	− 0.0008	− 0.0010	− 0.1885	+ 0.2469	
6.25	0.6812	− 0.2716	. . . . .	34	3	− 0.2713	. . . . .	− 0.0006	. . . . .	− 0.2719	. . . . .	
6.39	0.4113	. . . . .	+ 0.3444	18	4	. . . . .	+ 0.3442	. . . . .	− 0.0032	. . . . .	+ 0.3410	
7.39	0.7719	− 0.3005	. . . . .	19	3	− 0.3015	. . . . .	− 0.0028	. . . . .	− 0.3043	. . . . .	
8.18	0.8340	− 0.4212	. . . . .	24	5	− 0.4203	. . . . .	− 0.0024	. . . . .	− 0.4227	. . . . .	
The ends of both pipes are smooth and the edges square.												
RESULTS AT STATION NO. 3.												
0.64	0.7688	+ 0.0001	− 0.0005	61	4	0.0000	− 0.0006	. . . . .	. . . . .	0.0000	− 0.0006	Both pipes even with inside of Trough.
1.04	0.9105	− 0.0013	0.0000	90	6	− 0.0013	− 0.0001	. . . . .	. . . . .	− 0.0013	− 0.0001	" " " " "
1.76	0.7636	+ 0.0007	+ 0.0022	141	11	+ 0.0007	+ 0.0024	− 0.0001	− 0.0001	+ 0.0006	+ 0.0023	" " " " "

2.77	0.8732	+ 0.0014	+ 0.0022	200	19	+ 0.0013	+ 0.0022	— 0.0002	— 0.0002	+ 0.0011	+ 0.0020	Both pipes even with inside of Trough.
2.80	0.8798	— 0.0263	— 0.0028	24	2	— 0.0257	— 0.0024	— 0.0002	— 0.0002	— 0.0259	— 0.0026	West pipe projects 0.013 ft. East pipe even.
2.09	0.6722	— 0.0181	. . . . .	21	3	— 0.0185	. . . . .	— 0.0002	. . . . .	— 0.0187	. . . . .	,, ,, ,, ,, ,, ,,
2.41	0.6698	— 0.0224	— 0.0028	31	3	— 0.0207	— 0.0009	— 0.0002	— 0.0002	— 0.0209	— 0.0011	,, ,, ,, ,, ,, ,,
5.49	0.6199	— 0.1018	+ 0.0070	20	2	— 0.1018	+ 0.0070	— 0.0007	— 0.0007	— 0.1025	+ 0.0063	,, ,, ,, ,, ,, ,,
6.18	0.6890	— 0.1483	— 0.0028	42	4	— 0.1494	— 0.0041	— 0.0004	— 0.0005	— 0.1498	— 0.0046	,, ,, ,, ,, ,, ,,
7.65	0.7513	— 0.1791	+ 0.0157	42	3	— 0.1792	+ 0.0144	— 0.0023	— 0.0023	— 0.1815	+ 0.0121	,, ,, ,, ,, ,, ,,
8.35	0.8175	— 0.2178	+ 0.0170	18	3	— 0.2175	+ 0.0144	— 0.0021	— 0.0021	— 0.2196	+ 0.0123	,, ,, ,, ,, ,, ,,
7.97	0.8554	— 0.2097	+ 0.0141	55	6	— 0.2107	+ 0.0123	— 0.0018	— 0.0018	— 0.2125	+ 0.0105	,, ,, ,, ,, ,, ,,
7.95	0.8642	— 0.4379	+ 0.0020	7	2	— 0.4374	+ 0.0027	— 0.0018	— 0.0018	— 0.4392	+ 0.0009	West pipe projects 0.055 ft. ,, ,,
7.98	0.8610	. . . . .	— 0.1065	24	4	. . . . .	— 0.1062	. . . . .	— 0.0018	. . . . .	— 0.1080	and draws air in. East pipe projects 0.008 ft.
7.86	0.8673	— 0.0697	— 0.1805	30	3	— 0.0683	— 0.1779	— 0.0018	— 0.0018	— 0.0701	— 0.1797	West pipe projects 0.007 ft. East pipe projects 0.012 ft.
7.02	0.5575	— 0.0513	. . . . .	71	11	— 0.0512	. . . . .	— 0.0019	. . . . .	— 0.0531	. . . . .	,, ,, ,,

West pipe has its end parallel with side of trough.
East pipe, up-stream edge projects 0.0009 ft. more into trough than down-stream edge, and top projects 0.0002 ft. more than bottom.

Results at Station No. 4.

0.64	0.7646	+ 0.0002	— 0.0004	45	3	+ 0.0002	— 0.0002	. . . . .	. . . . .	+ 0.0002	— 0.0002	Four orifices open.
1.06	0.9078	— 0.0004	— 0.0004	124	7	— 0.0002	— 0.0003	. . . . .	. . . . .	— 0.0002	— 0.0003	,, ,, ,,
1.78	0.7513	— 0.0007	+ 0.0002	169	14	— 0.0008	+ 0.0003	— 0.0001	— 0.0001	— 0.0009	+ 0.0002	0.083 ft. orifice and 0.021 ft. orifice, open.
2.84	0.8498	— 0.0004	+ 0.0008	142	14	— 0.0005	+ 0.0005	— 0.0002	— 0.0002	— 0.0007	+ 0.0003	,, ,, ,, ,, ,,
5.47	0.6173	+ 0.0020	— 0.0038	47	4	+ 0.0016	— 0.0052	— 0.0009	— 0.0009	+ 0.0007	— 0.0061	,, ,, ,, ,, ,,
6.17	0.6875	— 0.0069	— 0.0178	45	4	— 0.0080	— 0.0195	- 0.0006	— 0.0006	— 0.0086	— 0.0201	,, ,, ,, ,, ,,
6.76	0.3843	+ 0.0103	+ 0.0079	20	3	+ 0.0102	+ 0.0073	— 0.0027	— 0.0027	+ 0.0075	+ 0.0046	0.083 ft. orifice and 0.042 ft. orifice open.
7.21	0.5500	+ 0.0033	+ 0.0097	54	6	+ 0.0035	+ 0.0100	— 0.0023	— 0.0023	+ 0.0012	+ 0.0077	0.083 ft. orifice, 0.042 ft. orifice, and 0.021 ft. orifice, open
7.79	0.7379	+ 0.0049	— 0.0155	59	6	+ 0.0049	— 0.0155	— 0.0030	— 0.0030	+ 0.0019	— 0.0185	,, ,, ,, ,, ,, ,, ,,
8.04	0.8551	— 0.0021	+ 0.0088	82	9	— 0.0019	+ 0.0093	— 0.0023	— 0.0023	— 0.0042	+ 0.0070	,, ,, ,, ,, ,, ,, ,,
8.32	0.8130	— 0.0067	+ 0.0020	18	3	— 0.0052	+ 0.0047	— 0.0026	— 0.0026	— 0.0078	+ 0.0021	,, ,, ,, ,, ,, ,, ,,

West side of trough slightly convex towards the middle, ordinate 0.002 ft. in 4 ft. Edge of orifice satisfactorily in surface of trough, but a slight burr at the edge can be drawn out by the finger.
East side of trough is straight, and the edges of orifices are as near in the plane as if in metal.

SUMMARY OF RESULTS AT STATIONS No. 5, No. 6, AND No. 7.

Mean velocity of water passing the Station.	Mean depth of water in the Trough.	Mean of observed heights of the surface of water in the still-boxes above the surface of the middle of the stream. At the West Still-box.	Mean of observed heights of the surface of water in the still-boxes above the surface of the middle of the stream. At the East Still-box.	No. of Obser-vat'ns.	No. of Experi-ments.	Mean of observed heights from which the third and fourth columns were obtained, corrected for the variation in height occurring in the interval of time between consecutive experiments. At the West Still-box.	Mean of observed heights … At the East Still-box.	Correction for slope of the surface of the stream between the point where the height was observed and a point opposite the centre of orifice communicating with Still-box. At the West Still-box.	Correction for slope … At the East Still-box.	Corrected mean height of surface of water in the Still-box above the surface of the middle of the stream opposite the centre of orifice communicating with Still-box. At the West Still-box.	Corrected mean height … At the East Still-box.	REMARKS.
Results at Station No. 5.												
Ft. per sec.	Feet.	Feet.	Feet.			Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	
0.63	0.7672	− 0.0005	− 0.0008	60	2	− 0.0005	− 0.0010	. . . . .	. . . . .	− 0.0005	− 0.0010	
1.05	0.9061	0.0000	− 0.0004	88	6	− 0.0001	− 0.0005	. . . . .	. . . . .	− 0.0001	− 0.0005	
1.79	0.7484	− 0.0001	+ 0.0017	133	14	+ 0.0001	+ 0.0019	− 0.0001	− 0.0001	0.0000	+ 0.0018	
2.88	0.8369	0.0000	+ 0.0017	132	12	− 0.0003	+ 0.0013	− 0.0002	− 0.0002	− 0.0005	+ 0.0011	
5.46	0.5883	+ 0.0117	+ 0.0138	57	4	+ 0.0108	+ 0.0116	− 0.0006	− 0.0007	+ 0.0102	+ 0.0109	
6.10	0.7027	+ 0.0038	+ 0.0056	12	1	+ 0.0036	+ 0.0059	− 0.0007	− 0.0007	+ 0.0029	+ 0.0052	
7.05	0.3715	+ 0.0103	+ 0.0146	25	4	+ 0.0100	+ 0.0141	− 0.0022	− 0.0024	+ 0.0078	+ 0.0117	
7.97	0.7114	+ 0.0186	+ 0.0263	35	3	+ 0.0180	+ 0.0255	− 0.0023	− 0.0025	+ 0.0157	+ 0.0230	
8.55	0.8037	+ 0.0215	+ 0.0317	25	4	+ 0.0217	+ 0.0315	− 0.0021	− 0.0023	+ 0.0196	+ 0.0292	

On the West side, the top and bottom of the orifice and the down-stream edge are in the plane of the side of trough, but the up-stream edge recedes 0.0008 ft. at the middle.

On the East side, the plane of the side of trough for a distance of 0.5 ft. up stream from the orifice, continued across, would cut into the down-stream side of orifice 0.0002 ft. for about two-thirds of the lower part of its height.

Results at Station No. 6.

0.65	0.7647	− 0.0023	+ 0.0018	180	8	− 0.0022	+ 0.0018	. . . . .	. . . . .	− 0.0022	+ 0.0018	
1.96	0.9060	− 0.0043	+ 0.0084	58	3	− 0.0044	+ 0.0083	. . . . .	. . . . .	− 0.0044	+ 0.0083	
1.82	0.7374	− 0.0126	+ 0.0260	102	8	− 0.0126	+ 0.0261	− 0.0001	− 0.0002	− 0.0127	+ 0.0259	
1.89	0.3709	− 0.0122	+ 0.0282	36	4	− 0.0110	+ 0.0298	− 0.0001	− 0.0003	− 0.0111	+ 0.0295	
2.32	0.4736	− 0.0181	+ 0.0413	36	4	− 0.0177	+ 0.0421	− 0.0001	− 0.0003	− 0.0178	+ 0.0418	
2.68	0.6067	− 0.0179	+ 0.0622	18	2	− 0.0169	+ 0.0653	− 0.0001	− 0.0003	− 0.0170	+ 0.0650	
3.01	0.8094	− 0.0327	+ 0.0725	131	12	− 0.0325	+ 0.0727	− 0.0001	− 0.0005	− 0.0326	+ 0.0722	
5.63	0.5929	− 0.1084	+ 0.2472	44	3	− 0.1096	+ 0.2446	− 0.0006	− 0.0013	− 0.1102	+ 0.2433	
6.08	0.7101	− 0.1297	+ 0.2705	30	2	− 0.1296	+ 0.2700	− 0.0007	− 0.0012	− 0.1303	+ 0.2688	
7.11	0.3710	. . . . .	+ 0.3505	11	3	. . . . .	+ 0.3501	. . . . .	− 0.0036	. . . . .	+ 0.3665	
7.54	0.5264	− 0.1734	. . . . .	42	7	− 0.1732	. . . . .	− 0.0028	. . . . .	− 0.1760	. . . . .	Air draws into the West tube at times.
8.13	0.7062	− 0.2116	. . . . .	12	2	− 0.2121	. . . . .	− 0.0020	. . . . .	− 0.2141	. . . . .	
8.21	0.8332	− 0.2122	. . . . .	84	12	− 0.2126	. . . . .	− 0.0029	. . . . .	− 0.2155	. . . . .	
8.59	0.8061	− 0.2458	. . . . .	11	3	− 0.2459	. . . . .	− 0.0023	. . . . .	− 0.2482	. . . . .	

On the West side, the plate does not vary more than 0.0003 ft. from the plane of the side of trough.
On the East side, the plate does not vary more than 0.0002 ft. from the plane of the side of trough.

Results at Station No. 7.

0.65	0.7640	0.0000	+ 0.0003	120	4	− 0.0001	+ 0.0001	. . . . .	. . . . .	− 0.0001	+ 0.0001
1.07	0.9019	+ 0.0003	− 0.0009	77	5	− 0.0002	− 0.0010	. . . . .	. . . . .	− 0.0002	− 0.0010
1.84	0.7313	+ 0.0001	+ 0.0014	162	13	0.0000	+ 0.0014	− 0.0001	− 0.0001	− 0.0001	+ 0.0013
3.11	0.7813	+ 0.0012	+ 0.0037	113	11	+ 0.0010	+ 0.0034	− 0.0001	− 0.0001	+ 0.0009	+ 0.0083
5.58	0.5922	− 0.0049	+ 0.0051	45	4	− 0.0061	+ 0.0040	− 0.0007	− 0.0007	− 0.0068	+ 0.0033
6.08	0.7059	− 0.0067	+ 0.0020	30	3	− 0.0075	+ 0.0013	− 0.0008	− 0.0008	− 0.0083	+ 0.0005
8.24	0.6983	− 0.0137	+ 0.0201	33	3	− 0.0139	+ 0.0203	− 0.0024	− 0.0024	− 0.0163	+ 0.0179
8.65	0.8046	− 0.0332	+ 0.0145	11	2	− 0.0334	+ 0.0145	− 0.0025	− 0.0025	− 0.0359	+ 0.0145

The edges of both orifices are well in the plane of the sides of the trough.
The up-stream edge of the west orifice and the down-stream edge of east orifice are slightly ragged, but do not project inside of trough.

SUMMARY OF RESULTS AT STATIONS No. 8, No. 9, AND No. 10.

Mean velocity of water passing the Station.	Mean depth of water in the Trough.	Mean of observed heights of the surface of water in the still-boxes above the surface of the middle of the stream.		No. of Observ'ns.	No. of Experiments.	Mean of observed heights from which the third and fourth columns were obtained, corrected for the variation in height occurring in the interval of time between consecutive experiments.		Correction for slope of the surface of the stream between the point where the height was observed and a point opposite the centre of orifice communicating with Still-box.		Corrected mean height of the surface of water in the Still-box above the surface of the middle of the stream opposite the centre of orifice communicating with Still-box.		REMARKS.
		At the West Still-box.	At the East Still-box.			At the West Still-box.	At the East Still-box.	At the West Still-box.	At the East Still-box.	At the West Still-box.	At the East Still-box.	
Results at Station No. 8.												
Ft. per sec.	Feet.	Feet.	Feet.			Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	
0.65	0.7611	− 0.0007	− 0.0003	93	4	− 0.0007	− 0.0004	. . . . .	. . . . .	− 0.0007	− 0.0004	Four orifices open.
5.76	0.5957	+ 0.0082	+ 0.0053	49	4	+ 0.0077	+ 0.0048	− 0.0006	− 0.0006	+ 0.0071	+ 0.0042	0.042 ft. orifice and 0.083 ft. orifice, open.
7.49	0.3563	+ 0.0131	. . . . .	12	3	+ 0.0125	. . . . .	− 0.0021	. . . . .	+ 0.0104	. . . . .	0.021 ft. orifice in use.
7.76	0.5239	+ 0.0190	+ 0.0048	35	4	+ 0.0194	+ 0.0055	− 0.0018	− 0.0018	+ 0.0176	+ 0.0037	0.021 ft. orifice, 0.042 ft. orifice, and 0.083 ft. orifice, open.
8.36	0.6898	+ 0.0155	+ 0.0072	53	4	+ 0.0149	+ 0.0063	− 0.0023	− 0.0023	+ 0.0126	+ 0.0040	" " " " " " "
8.39	0.8186	+ 0.0164	+ 0.0040	78	9	+ 0.0166	+ 0.0046	− 0.0018	− 0.0018	+ 0.0148	+ 0.0028	" " " " " " "
8.77	0.7826	+ 0.0192	+ 0.0060	17	3	+ 0.0183	+ 0.0044	− 0.0021	− 0.0021	+ 0.0162	+ 0.0023	" " " " " " "

All the edges of orifices are very satisfactorily in the plane of the Trough.

Results at Station No. 9.

0.64	0.7650	− 0.0008	− 0.0003	103	5	− 0.0003	− 0.0004	.....	.....	− 0.0008	− 0.0004
1.09	0.8966	− 0.0001	− 0.0009	104	6	0.0000	− 0.0007	.....	.....	0.0000	− 0.0007
1.86	0.7178	− 0.0004	− 0.0002	106	10	− 0.0005	− 0.0004	.....	− 0.0001	− 0.0005	− 0.0005
3.31	0.7322	− 0.0023	− 0.0007	114	11	− 0.0022	− 0.0006	− 0.0001	− 0.0001	− 0.0023	− 0.0007
5.79	0.5702	+ 0.0011	+ 0.0034	47	4	+ 0.0001	+ 0.0017	− 0.0006	− 0.0007	− 0.0005	+ 0.0010
6.14	0.6987	+ 0.0008	+ 0.0046	46	5	− 0.0001	+ 0.0031	− 0.0006	− 0.0007	− 0.0007	+ 0.0024
7.57	0.3474	.....	+ 0.0039	12	3	.....	+ 0.0023	.....	− 0.0021	.....	+ 0.0002
8.44	0.6766	− 0.0041	+ 0.0036	34	3	− 0.0045	+ 0.0032	− 0.0022	− 0.0023	− 0.0067	+ 0.0009
8.88	0.7835	− 0.0054	− 0.0003	17	3	− 0.0032	+ 0.0049	− 0.0021	− 0.0023	− 0.0053	+ 0.0026

On the West side, the lower up-stream corner of orifice projects into the trough 0.0015 ft. The other corners are satisfactorily in the plane of the Trough.
On the East side, the edges of the orifice are very satisfactorily in the plane of the Trough.

Results at Station No. 10.

0.62	0.7627	0.0000	− 0.0002	141	5	+ 0.0001	− 0.0002	.....	.....	+ 0.0001	− 0.0002
1.06	0.8948	+ 0.0001	− 0.0006	183	9	+ 0.0001	− 0.0006	.....	.....	+ 0.0001	− 0.0006
1.90	0.7081	+ 0.0013	+ 0.0006	157	14	+ 0.0013	+ 0.0007	− 0.0001	− 0.0001	+ 0.0012	+ 0.0006
3.54	0.6901	+ 0.0028	− 0.0020	110	11	+ 0.0027	− 0.0021	− 0.0003	− 0.0003	+ 0.0024	− 0.0024
5.67	0.6639	+ 0.0242	+ 0.0060	50	4	+ 0.0222	+ 0.0022	− 0.0007	− 0.0007	+ 0.0215	+ 0.0015
6.06	0.7089	+ 0.0226	+ 0.0034	46	5	+ 0.0221	+ 0.0026	− 0.0007	− 0.0007	+ 0.0214	+ 0.0019
7.63	0.3462	+ 0.0234	− 0.0007	18	3	+ 0.0229	− 0.0011	− 0.0023	− 0.0023	+ 0.0206	− 0.0034
7.81	0.4893	+ 0.0361	+ 0.0032	27	3	+ 0.0355	+ 0.0024	− 0.0021	− 0.0021	+ 0.0334	+ 0.0003
8.51	0.6783	+ 0.0407	+ 0.0018	31	3	+ 0.0398	+ 0.0007	− 0.0024	− 0.0024	+ 0.0374	− 0.0017
8.75	0.7774	+ 0.0442	− 0.0012	11	2	+ 0.0442	− 0.0012	− 0.0026	− 0.0026	+ 0.0416	− 0.0038

The edges of orifices are satisfactory. Their planes are parallel with sides of trough, and are back from them 0.0003 ft. or 0.0004 ft. on each side.

The following notes were made at Station No. 4, when the mean velocity of the stream was eight feet per second: —

10^{h} 9′. There is a depression in surface of stream about 0.5 ft. below Sta. No. 3; and a swell at 0.85 ft. above Sta. No. 4. Distance from swell to depression, 1.15 ft.

11′. Depression 0.3 ft. below Sta. No. 4, and swell 1.3 ft. below Sta. No. 4. Distance, 1 ft.

12′. I should judge that the swell above Sta. No. 4 is about 0.02 ft. above the line connecting the depressions.

The depression and swell move longitudinally, frequently about one-half a foot, and more rarely to the extent of replacing each other.

22′. There is continual change in height of surface, but noticeable fluctuations come as often as three-quarters of a second, and from 0.01 ft. to 0.02 ft. in height.

34′. There is a swaying of the highest part of the stream from side to side; generally from within a tenth of a foot from one side to a tenth of a foot from the other, but occasionally running nearer the side.

36′. There are times when the surface is quite even from side to side, and again it will vary as much as 0.02 ft.

38′. A swell longitudinally follows this fluctuation from side to side, but is not a swell the full width of the stream.

39′. The swell seems to be a twisting of the thread of the current from one side of the trough to the other.

41′. In the cross section there is a rise of the surface on each side, and a rise of the thread of the stream for a width of about 0.06 ft., and a depression each side of this.

Immediately after the above observations, the following were made at Station No. 8, in the midst of the series of eleven experiments, having a mean velocity of 8.39 ft. per second.

10^{h} 46′. The longitudinal distances between the swells and depressions are greater near Sta. No. 8 than at Sta. No. 4, but are less definite. The variation in height is at times as much as 0.02 ft.

52′. The surface of the stream is much more even here than at Sta. No. 4. There is no marked rise near the middle of the stream, but there is a swaying of the highest part of the stream from side to side about 0.01 ft.

54′. The line of air-bubbles is nearly obliterated, varying to 0.04 ft. each side of the middle, but most of the time remaining on the east side of the middle.

Orifices in the Plane of Side. Passages normal.

The results obtained with orifices whose edges do not vary perceptibly from the plane of the side of the trough, with passages normal to this plane will first be considered. Such are found on both sides at Station No. 4, on both sides at Station No. 8, and on the east side at Station No. 9.

Mean velocity of water passing the Stations.		Mean heights of surface of water in the still-boxes above the surface of the middle of the stream, multiplied by the number of observations.										Sum of the products expressed in the preceding columns.	No. of obser-vat'ns.	Average heights, or sum of products divided by number of observations.
		Station No. 4.				Station No. 8.				Station No. 9.				
From.	To.	At the West Still-box.		At the East Still-box.		At the West Still-box.		At the East Still-box.		At the East Still-box.				
Ft. per second.	Ft. per second.	Heights. Feet.	No. of Obs.	Heights. Feet.	No. of Obs.	Heights. Feet.	No. of Obs.	Heights. Feet.	No. of Obs.	Heights. Feet.	No. of Obs.			
0.64	0.65	+ 0.0002 ×	22	— 0.0002 ×	23	— 0.0007 ×	46	— 0.0004 ×	47	— 0.0004 ×	51	— 0.0762	189	— 0.0004
1.06	1.09	— 0.0002 ×	62	— 0.0003 ×	62	. . . .		. . . .		— 0.0007 ×	52	— 0.0674	176	— 0.0004
1.78	1.86	— 0.0009 ×	84	+ 0.0002 ×	85	. . . .		. . . .		— 0.0005 ×	58	+ 0.0851	222	— 0.0004
2.84	3.81	— 0.0007 ×	71	+ 0.0003 ×	71	. . . .		. . . .		— 0.0007 ×	57	— 0.0683	199	— 0.0003
5.47	5.79	+ 0.0007 ×	23	— 0.0061 ×	24	+ 0.0071 ×	24	+ 0.0042 ×	25	+ 0.0010 ×	24	+ 0.1691	120	+ 0.0014
6.17	6.14	— 0.0086 ×	22	— 0.0201 ×	23	. . . .		. . . .		+ 0.0024 ×	23	— 0.5963	68	— 0.0088
6.76	7.57	+ 0.0075 ×	7	+ 0.0046 ×	13	+ 0.0104 ×	12	. . . .		+ 0.0002 ×	12	+ 0.2395	44	+ 0.0054
7.21	7.76	+ 0.0012 ×	27	+ 0.0077 ×	27	+ 0.0176 ×	17	+ 0.0087 ×	18	. . . .		+ 0.6061	89	+ 0.0068
7.79	8.44	+ 0.0019 ×	29	— 0.0185 ×	30	+ 0.0126 ×	26	+ 0.0040 ×	27	+ 0.0009 ×	17	— 0.0490	129	— 0.0004
8.04	8.39	— 0.0042 ×	41	+ 0.0070 ×	41	+ 0.0148 ×	39	+ 0.0028 ×	39	. . . .		+ 0.8012	160	+ 0.0050
8.32	8.88	— 0.0078 ×	9	+ 0.0021 ×	9	+ 0.0162 ×	8	+ 0.0023 ×	9	+ 0.0026 ×	9	+ 0.1214	44	+ 0.0028
												+ 0.9950	1440	+ 0.0007

Combining the results obtained at these orifices, grouping those made at the same time or under like circumstances, and giving to each a weight proportioned to the number of observations from which it is obtained, we have the general results contained in the foregoing table.

These average heights are represented in Fig. 1, Plate No. 3. In this Plate and in Plate No. 4, the horizontal lines represent the surface of the stream; the ordinates are the heights expressed in full scale or in actual distances above and below this surface; and the abscissas are mean velocities, in which one foot per second is expressed by one twenty-fourth of a foot.

Taking a general view of these average heights, we find five results are positive and six are negative; and the general average height of all, or the sum of the products of each height multiplied by its number of observations, divided by the whole number of observations, gives for the 1440 observations, the height of the surface of water in the still-boxes, 0.0007 ft. above that of the surface of the middle of the stream.

Examining more in detail, we find that, with mean velocities up to four feet per second, the heights of the surfaces in the still-boxes and those at the middle of the stream coincide, within the practicable limits of measurement. With velocities from five feet to nearly nine feet per second, the heights of surfaces in the still-boxes are both above and below those of the middle of the stream by measurable quantities.

If we now assume, for the purpose of comparison, that, if there is any real difference in these heights dependent upon the velocity, it will vary with the square of the velocity; and assuming also that the incessant fluctuations of the surface of the stream vary in height with the square of the velocity of the stream, it will be found by plotting these heights with their respective velocities, and giving to each a weight corresponding with the number of observations made in determining it, that they will be represented by a line expressing the height of the surface of the still-boxes above that of the stream by 0.000035 of the square of the velocities of the stream; or a little more than two-tenths of one per cent of the heads which would produce these velocities, and but twelve per cent of the extent of the incessant fluctuations in height of the surface of the stream.

This result proves that, with these orifices cut with care in pine planks, having their passages at right angles with the side of the trough, and having their edges so nearly in the plane of the side of

the trough that careful observation detected no variation therefrom, and having areas in circular form from 0.0003 sq. ft. to 0.0054 sq. ft., and one rectangular area having a height of 0.083 ft. and a length of 0.334 ft., there was no lowering of the piezometric column by cohesion of the water acting at its base; and shows that the height of the piezometric column was in excess of that of the stream by an amount extremely small, but with large velocities it was within the practicable limits of observation.

Orifices slightly inclined. Passages normal.

Before concluding the result just obtained to be a general truth, it is important to learn in what manner it will be affected by slight modifications of the conditions under which it was obtained. These are fortunately presented, probably through unequal swelling of the wood, in the orifices on each side at Station No. 5, and at the west orifice at Station No. 9.

After the experiments were made, those with high velocities being recently completed, these orifices were found to be in the following condition: —

At Station No. 5, the orifice upon the west side being a rectangle 0.337 ft. high and 0.084 ft. wide, horizontally, had its top, bottom, and down-stream edges well in the plane of the side of the trough; but the up-stream edge, being in this plane at the top and bottom, receded from it 0.0008 ft. at its mid height. The orifice upon the east side, being a rectangle 0.336 ft. high and 0.021 ft. wide, horizontally, was in the condition that the plane of the side of the trough for half a foot up stream from the orifice continued across it would cut into the down-stream side of the orifice about 0.0002 ft. back from its edge, for about two-thirds of the lower part of its height.

It is probable that these variations from a plane increased during the three months in which the experiments were made, in which case the condition presented is not applicable to the earlier experiments with small velocities.

At Station No. 9, the orifice in the west side was cut 0.168 ft. high and 0.250 ft. long, and then filled for the up stream one-third of its length by a block, leaving a square orifice. At the end of experiments, the edges of the original orifice were found to be in the plane of the side of the trough, and the up-stream and top edges of the block were also in this plane; but the lower down-stream corner of the block, and consequently the lower end of the up-stream edge of the orifice, projected into the trough 0.0015 ft.

With these three orifices, the horizontal elements of the surfaces, bounded by their edges, vary from being parallel with the axis of the stream to a maximum deviation therefrom of 0° 33′ in each of the orifices at Station No. 5, and of 0° 31′ at Station No. 9.

The direction of the deviation of the surfaces being such that at Station No. 5 the particles of water in passing would impinge upon it, and at Station No. 9 they would withdraw from it.

The effect of these slight deviations is presented in the following table, and in Fig. No. 2 of Plate No. 3: —

STATION No. 5. *West Side.*

Mean velocity of water passing the Station. U Ft. per second.	Mean heights of the surface in still-box above that at the middle of the stream. Heights. Feet.	No. of Obs.	$0.0002\ U^2$
0.63	−0.0005	30	0.0001
1.05	−0.0001	44	0.0002
1.79	0.0000	66	0.0006
2.88	−0.0005	61	0.0017
5.46	+0.0102	28	0.0060
6.10	+0.0029	6	0.0074
7.05	+0.0078	12	0.0099
7.97	+0.0157	17	0.0127
8.55	+0.0196	12	0.0150

STATION No. 5. *East Side.*

Mean velocity of water passing the Station. U Ft. per second.	Mean heights of the surface in still-box above that at the middle of the stream. Heights. Feet.	No. of Obs.	$0.00032\ U^2$
0.63	−0.0010	30	0.0001
1.05	−0.0005	44	0.0003
1.79	+0.0018	67	0.0010
2.88	+0.0011	61	0.0027
5.46	+0.0109	29	0.0095
6.10	+0.0052	6	0.0119
7.05	+0.0117	18	0.0159
7.97	+0.0230	18	0.0203
8.55	+0.0292	18	0.0240

STATION No. 9. *West Side.*

			$0.00008\ U^2$
0.64	−0.0003	51	0.0000
1.09	0.0000	52	0.0001
1.86	−0.0005	53	0.0003
3.31	−0.0023	57	0.0009
5.79	−0.0005	23	0.0027
6.14	−0.0007	23	0.0030
8.44	−0.0067	17	0.0057
8.88	−0.0053	8	0.0063

From these results, we see that, where the surface included by the edges of the orifice is turned, even very slightly, so that the particles of water flowing parallel with the axis of the stream strike into it, the surface of water in the piezometer stands higher than the surface

of the stream; and, when turned so that the particles of water withdraw from it, the surface of the piezometer stands lower than the surface of the stream. Assuming that the variation is as the square of the mean velocity of the stream, the excess in height of the piezometric surface at the west box of Station No. 5 may be expressed approximately by heights equal to $0.0002\,U^2$, in which U stands for the mean velocity of the stream at the station; and the excess in height at the east box of Station No. 5 may be expressed approximately by heights equal to $0.00032\,U^2$; and the depression at Station No. 9 may in like manner be expressed by $0.00008\,U^2$.

Orifices parallel. Passages inclined.

At Stations No. 7 and No. 10, the planes of the edges of the orifices were, within the limits of careful observation, either in the plane of the sides of the trough, as at Station No. 7, or parallel with this plane, and within 0.0004 ft. from it, as at Station No. 10; but at these stations the passages from the orifices, beginning at the plane of their edges, were not normal to this plane, but made therewith an acute horizontal angle.

At Station No. 7, on the west side, the angle was 45° up stream, and on the east side was 45° down stream. At Station No. 10, on the west side, the angle was 30° down stream, and on the east side was 30° up stream.

At Station No. 7, the orifices were made by boring through the sides of the trough, at the proper angle, holes 0.021 ft. in diameter; and, though cut with great care, it was found at the end of the experiments that the acute edge of each was slightly ragged, but no projection into the trough was perceptible.

At Station No. 10, the orifices were made with the same sized hole in plates of brass, carefully finished, and set into the sides of the trough flush; but the swelling of the wood in the thickness of the plate, which was 0.01 ft., caused it to project 0.0003 ft. or 0.0004 ft. beyond the surface of the plates all around. The plates were 0.083 ft. high and 0.125 ft. long.

The results given in the tables for these stations are represented in Fig. No. 3, Plate No. 3.

Here we see that on the east side at Station No. 7, and on the west side at Station No. 10, in which cases the particles of water turning 45° and 30° respectively from their course would flow directly through the passage into the piezometric reservoirs, the surfaces of the reservoirs stand higher than the surface of the stream,

and these heights may be expressed approximately at Station No. 7 by 0.0002 U^2, and at Station No. 10 by 0.0005 U^2.

On the other hand, on the west side at Station No. 7 and east side at Station No. 10, where the passages go out up stream, the surface of the piezometric reservoir at Station No. 7 stands lower than the surface of the stream by amounts expressed approximately by 0.00025 U^2. While at Station No. 10, the surface in the reservoir is slightly above and below that of the stream, in no case more than 0.004 ft., and the mean result for all of the velocities is very nearly zero.

If there were any lowering of the piezometer by the action of cohesion at its base, it would follow that with orifices having passages so very favorable to drawing water from the reservoir, as in the two cases just considered, the lowering would be much greater than the raising above the stream in the two previous cases; but the lowering being really less than the raising tends to the conclusion that there is no lowering due to cohesion at the orifice.

The raising of the piezometric column three per cent of the head that would produce the velocity of the stream, and the lowering of one and one-half per cent of the same head by the difference in direction of the passage, without any perceptible variation of the plane of the orifice from that of the side, indicate that, either from imperceptible variations in the plane of the orifice, or from sinuosity of current, such inclined passages are not to be relied upon for accurate results.

Orifices projecting into the Stream. Passages inclined.

At Station No. 2, a hole was bored through each side of the trough, making with the inner face a horizontal angle of 48°, up stream on the west side and down stream on the east side. Into these holes were fitted brass pipes, 0.049 ft. in diameter outside, and 0.043 ft. in diameter inside, having the inner ends finished smooth with square edges. These pipes projected into the trough, so that the intersection of the plane of the end of each with the plane of the side of the trough was very nearly a tangent to the outer circumference of the end.

The distance from the plane of the side to the point of the outer circumference of the end farthest removed was 0.033 ft., and to the corresponding point of the inner circumference was 0.031 ft.

At Station No. 6 were other projections into the trough. Two brass castings were made, each consisting of a plate 0.083 ft. high,

0.125 ft. long, and 0.010 ft. thick, having near the middle of one side a projection of about 0.02 ft., through which was drilled, lengthwise of the plate at an angle of 30° with its face, a hole 0.021 ft. in diameter. The end of the hole was finished at right angles with its axis, having the circumference very nearly tangent to the surface of the plate; and, the edge of the orifice being as thin as practicable, the outside of the projection was finished, making its elements diverge 10° from the axis of the hole, and its point farthest removed from the plane of the plate was 0.02 ft. therefrom.

When in position in the trough, the face of the plate was in the plane of the side; and a horizontal section through the axis shows the inside of the hole, making an angle of 30°, and the outside of the projection one of 20° with the side. The orifice faced down stream on the west side and up stream on the east side. During experiments, the plates did not vary more than 0.0002 ft. and 0.0003 ft. from the plane of the side of the trough.

A short time before the experiments were completed, an instrument with projections, designed to be miniature models of those at Station No. 6, was set into the west side of the trough, 0.84 ft. up stream from Station No. 6, and 0.25 ft. above the bottom.

This instrument consisted of a circular plate of brass 0.147 ft. in diameter and 0.042 ft. thick, having a hole through its centre 0.013 ft. in diameter, normal to its face, with square edges well in the plane of its face. At 0.04 ft. above and below the central hole were two others, 0.005 ft. in diameter, drilled in horizontal planes through projections upon the face from opposite sides of the vertical through their centres; the hole above the centre making an angle of 30° with the face down stream, and that below making the same angle up stream.

The orifices were finished with thin edges, in planes normal to the axes, and were very nearly tangent to the face of the instrument, from which the entire projection was 0.005 ft. The elements of the outside surfaces were made to diverge 10° from the axes.

When in place in the trough, the face of the instrument was not more than 0.0002 ft from the plane of the side. Short brass tubes were screwed into the back of the instrument and connected with vertical glass tubes placed against a scale upon which the heights of water surfaces were read.

The results obtained at Stations No. 2 and No. 6 and with the instrument just described are given in the following table: —

Mean velocity of stream passing the orifice. U. Ft. per sc.	Number of observations.	Height of the surface in the still-boxes above that of the middle of the stream. At the West Still-box. Feet.	At the East Still-box. Feet.		
At Station No. 2.				$-0.0063\,U^2$	$+0.0086\,U^2$
0.64	60	−0.0025	+0.0030	−0.0026	+0.0035
1.08	148	−0.0068	+0.0100	−0.0067	+0.0091
1.74	108	−0.0201	+0.0223	−0.0191	+0.0260
2.70	119	−0.0412	+0.0664	−0.0459	+0.0627
5.23	56	−0.1885	+0.2469	−0.1723	+0.2352
6.25	84	−0.2719	......	−0.2461	......
6.39	18	......	+0.3410	......	+0.3511
7.39	19	−0.3048	......	−0.3440	......
8.18	24	−0.4227	......	−0.4215	......
At Station No. 6.				$-0.0038\,U^2$	$+0.0074\,U^2$
0.65	180	−0.0022	+0.0018	−0.0014	+0.0031
1.06	58	−0.0044	+0.0083	−0.0037	+0.0081
1.82	102	−0.0127	+0.0259	−0.0109	+0.0245
1.89	86	−0.0111	+0.0295	−0.0129	+0.0264
2.32	86	−0.0178	+0.0418	−0.0178	+0.0398
2.68	18	−0.0170	+0.0650	−0.0237	+0.0536
3.01	131	−0.0326	+0.0722	−0.0299	+0.0670
5.63	44	−0.1102	+0.2433	−0.1046	+0.2346
6.08	80	−0.1303	+0.2688	−0.1220	+0.2736
7.11	11	......	+0.3465	......	+0.3741
7.54	42	−0.1760 *	......	−0.1876	......
8.13	12	−0.2141	......	−0.2181	......
8.21	84	−0.2155	......	−0.2224	......
8.59	11	−0.2482	......	−0.2435	......
At Side Instrument above Station No 6.					
		Height of water above that of central glass tube. In down-stream Tube. Feet.	In up-stream Tube. Feet.	$-0.0025\,U^2$	$+0.0046\,U^2$
7.27	33	−0.1294	+0.2370	−0.1321	+0.2429
7.38	40	−0.1334	+0.2369	−0.1361	+0.2505
8.12	138	−0.1635	+0.3109	−0.1646	+0.3033

* Air drew into West tube at times.

These results are also represented graphically upon Plate No. 4, where it will be seen they may be expressed with a good degree of approximation in terms of the mean velocity of the stream, as follows: —

At Station No. 2.	
West side	$-0.0063\ U^2$
East side	$+0.0086\ U^2$
At Station No. 6.	
West side	$-0.0033\ U^2$
East side	$+0.0074\ U^2$
At Side Instrument near Station No. 6.	
Down-stream Tube	$-0.0025\ U^2$
Up-stream Tube	$+0.0046\ U^2$

In these results, we see that with the orifice inclined down stream the lowering of the reservoir below the surface of the stream is less in amount than the raising of the reservoir above the surface of the stream where the orifice is inclined up stream at the same angle; the former being in the three cases seventy-three, forty-four, and fifty-four per cent of the latter.

Orifices parallel. Passages normal. Tubes projecting.

At Station No. 3, holes were bored at right angles with the plane of the side, and into these were fitted iron pipes. On the west side, the pipe being 0.068 ft. in diameter outside, and 0.052 ft. in diameter inside, had a well finished end parallel with the plane of the side, with square edges. On the east side, the pipe was 0.109 ft. in diameter outside and 0.086 ft. in diameter inside, with end designed to be finished like that upon the west side; but it was not done with care, and the up-stream edge was, at the close of the experiments, found to project 0.0009 ft. farther into the stream than the down-stream edge, and the top edge to project 0.0003 ft. more than the bottom edge.

At first, both pipes were kept flush with, or without any projection beyond the plane of the side, and afterward were pushed out into the stream, as indicated in the table giving a summary of results at this station.

With velocities from 0.64 ft. to 2.77 ft. per sec., the westerly pipe being flush with the side, the average height in the reservoir is the same as that at the middle of the stream, within the practicable limits of measurement.

The same result obtains upon the east side up to velocities exceed-

ing 6 ft. per sec. With velocities between seven and one half feet and eight and one half feet per sec., the average height in the reservoir was greater than that at the middle of the stream by 0.0108 ft.

But, immediately upon projecting one of the pipes into the stream, a marked change is observed: the surface in the reservoir is immediately lowered; with a velocity of 2.77 ft. per sec., the westerly pipe being flush with the side, the surface in the reservoir was 0.0011 ft. higher than that in the stream, but, upon projecting this pipe 0.013 ft. into the stream, the surface in the reservoir immediately lowered to 0.0259 ft. below that of the stream; the mean velocity continuing 2.80 ft. per sec. With the same projection of 0.013 ft., with velocities from 2.09 ft. to 8.35 ft. per sec., the lowering of the surface of the reservoir below that of the stream increased from 0.0187 ft. to 0.2196 ft. in a series expressed approximately by heights equal to 0.0033 U^2, as shown in Fig. No. 4, Plate No. 3.

Increasing the projection to 0.055 ft., the mean velocity being 7.95 ft. per sec., the lowering of the reservoir was 0.4392 ft., or 0.0069 U^2; and it would probably have been more, but at this height the surface of the reservoir was drawn below the top of the pipe, even to its centre, and air was drawn into the stream.

The form of the stream of air at the orifice revealed to the eye the cause of the lowering in the reservoir. It was evident that the particles of water striking the up-stream side of the pipe were deviated in part nearly at a right angle toward the middle of the stream, and their course again bent down stream, forming a path approximating a quadrant of an ellipse whose conjugate axis lay in the end of the pipe parallel with the axis of the stream.

Upon withdrawing the pipe and reducing the projection to 0.007 ft., the lowering in the reservoir is expressed by 0.0011 U^2.

At the east side, with the pipe so placed that its most projecting point was in the plane of the side of the trough, and with a mean velocity of stream of 7.95 ft. per sec., the surface of water in the reservoir was 0.0009 ft. above that of the stream; but, upon projecting the pipe 0.008 ft., the surface in the reservoir was lowered to 0.1080 ft. below that of the stream, the mean velocity continuing 7.98 ft. per sec. This lowering may be expressed by 0.0017 U^2.

Upon projecting this pipe 0.012 ft., the lowering, with a mean velocity of 7.86 ft. per sec., amounted to 0.1797 ft., or 0.0029 U^2.

If we knew the actual distribution of velocities throughout the stream, it would be interesting to trace the relation of the lowering of the reservoir and the velocity of the stream just at the end of the pipe.

With our present knowledge, this cannot be done with accuracy; but from observations, which I will not describe, I am able to present an approximate result which will serve to illustrate one principle.

Taking, for example, the conditions when the mean velocity of the stream is 8 ft. per sec., I construct the following table: —

Distance from side of trough.	Approximate velocity at the distance given.	Head that would produce this approximate velocity.	Lowering of reservoir below surface of stream.	Lowering of reservoir divided by head producing approximate velocity.	Velocity due lowering. $V = \sqrt{2gh}$	Velocity due lowering divided by approximate velocity.
Feet.	Ft. per sec.	Feet.	Feet.		Ft. per sec.	
0.007	5.6	0.488	0.070	0.14	2.12	0.38
0.008	5.8	0.523	0.109	0.21	2.65	0.46
0.012	6.2	0.598	0.186	0.31	3.46	0.56
0.013	6.3	0.617	0.211	0.34	3.68	0.58
0.055	8.0	0.995	0.442	0.44	5.33	0.67

Recurring to the observations when the westerly tube projected 0.055 ft. and the paths of some of the particles were found to deviate about ninety degrees, and, passing through a quadrant of an ellipse, again resume a direction parallel with their former course, it would be reasonable to conclude that, with a projection of a few thousandths of a foot, the deviation of the paths would be less than ninety degrees, and the curve would be flattened, and become more like a segment taken nearer the transverse axis. In this case, the lowering of the reservoir would not bear a constant relation to the head which would produce the velocity existing at the end of the pipe, but would be a fraction of this head, increasing with the distance from the side, rapidly at first, and then slower, until reaching a limit would remain constant. This conclusion is confirmed by the results of the table, in which with distances from 0.007 ft. to 0.055 ft., the velocity due a height equal to the lowering of the reservoir increases from 0.38 to 0.67 of the velocity at the end of the pipe, and this increase is in a rapidly decreasing series.

I have reason to conclude, from experiments made elsewhere, that the lowering of the reservoir depends also upon the thickness of the end of the pipe; for I found by projecting a pipe 0.02 ft. in diameter, having very little thickness at the end, into water flowing in an iron pipe one foot in diameter, with a mean velocity of 9 ft. per sec., a lowering of the piezometric column greater than that above given; namely, for the same distances from the side, the velocity due a height equal to the lowering was from seventy to ninety one-hundredths

of the velocity with which the water approached the end of the pipe, and at greater distances the velocity due the lowering increased until it exceeded the velocity of the approaching water.

CONCLUSIONS.

From the 6000 and more observations made at this trough upon the various forms and kinds of orifices, I reach the following general conclusions: —

The first group of experiments shows that with orifices whose edges are in the plane of the side of the conduit, with passages normal to this plane, the surface of water in the piezometers does not stand below the surface of the stream.

On the contrary, the general results at the orifices of this kind indicate, for the higher velocities, an excess of height in the piezometer expressed by 0.000035 U^2.

This is but twelve per cent of the incessant fluctuation of the surface; but, though a very small quantity, it is, with the higher velocities experimented upon, a measurable one, and its cause is to be sought.

Experiments at Station No. 6 and those with the instrument having projections of 0.005 ft. show that the height above the surface of the stream to which water in the piezometer is forced is greater when the orifice is turned toward the current than the height below the surface to which it is drawn when the orifice is turned so that the stream draws away from it; in these cases nearly twice as great, the angle with the plane of the side and the amount of projection being the same when facing with or against the current. The observations at Station No. 5 and on the west side at Station No. 9 give a similar result.

The edges of the orifices of the first group of experiments which were, within the limits of careful observation, in the plane of the side of the trough, were of course not perfectly in this plane: the probabilities are that they deviated as much from this plane upon the down-stream side as upon the up-stream side, in which case it follows from the experiments just cited that the effect of these imperfections would give an average height of the piezometers greater than the height of the stream. If the comparative value of the excess of and diminution in height of the experiments cited be applied to these results, the average height of piezometers for velocities above 5 ft. per sec. will be reduced to the average height of the stream, within the practicable limits of measurement. This result indicates, with a nearness of approximation unusual in hydraulic investigations, that

with the plane of the orifice accurately in the plane of the side of the conduit the piezometer will indicate the true height of the surface of the stream.

The second group of experiments shows that, with extremely slight variations of the plane of the orifice from the plane of the side, the piezometer indicates a greater height or a less height than the surface of the stream, according as these variations cause the stream to strike into or draw away from the plane of the orifice; and, in connection with the experiments at Station No. 6 and elsewhere upon definitely formed projections, they lead quite definitely to the conclusion that with an orifice whose edges are in the plane of the side, and passage normal thereto, the piezometric column will stand neither above nor below the surface of the stream, but will indicate the true height of this surface.

The third group of experiments in which the plane of the orifice was in, or nearly in, the plane of the side, but the passage from it turned sharply up stream or sharply down stream, shows that, with such arrangement, variations from the plane of the side which would escape careful observation, or slight inclinations of the current, may lead to variations of considerable magnitude in height of the piezometric column above or below that of the surface of the stream, consequently such arrangements are not to be relied upon.

The fourth group of experiments in which the orifice projects into the stream, and the plane of its edges makes a large horizontal angle with the plane of the side, either up stream or down stream, shows that with the same angle and the same projection into the stream the piezometric column connected with the orifice facing up stream stands above the surface of the stream by a much greater amount than the piezometric column connected with the orifice facing down stream stands below the same surface; the latter height being, in the examples before us, from forty-four to seventy-three per cent of the former.

The fifth group of experiments in which pipes at right angles with the current project into the stream, the end of the pipe having square edges, shows that with such an arrangement the piezometric column stands lower than the surface of the stream.

This follows from the fact made evident that the particles of water which would pass where the pipe is are deviated from their course, a part of them moving lengthwise of the pipe, and, being projected in a curve around its end, cause the pressure into the end of the pipe to be diminished below that of the normal pressure upon the sides of the

trough, by an amount which is a varying fraction of the pressure which would produce the velocity with which the water approaches the pipe.

This fraction increases with the projection from the side, from zero to forty-four one-hundredths, in the experiments in this trough; and in the experiments alluded to in a closed conduit under pressure, with a smaller pipe having a thin end, it increased more rapidly with the same distances from the side, and with greater distances increased until the lowering exceeded the height which would produce the velocity of the approaching water.

The lowering of the piezometric column under circumstances like these just presented confirmed Dubuat * in his conclusion that water in motion pressed upon the sides of a conduit with a pressure less than that due its depth, by the whole amount of pressure that would produce its mean velocity, which conclusion Navier † controverted, but which has been presented in works upon hydraulics quite generally until the publication of the results of M. Darcy, which in general confirmed the position of Navier, but left in doubt the indications of the piezometer; but the experiments now presented show that with currents flowing parallel with the side of a straight conduit, with orifices having edges in the plane of the side and with passages normal thereto, there is no lowering of the piezometric column, but that it indicates the true height of the surface of the water in the conduit when in motion, as well as when at rest. And we have a reliable datum plane, to which observations in hydraulics may be referred.

Note. Upon the Limits of Accuracy that may be obtained with Piezometers.

The experiments of the first group were united, because from careful observation, made before any results were computed, the planes of the orifices were regarded as satisfactorily in the plane of the side. No deviation therefrom was perceptible in the light in which they could be seen that enabled me to say they inclined one way or the other. This light was good upon the side of the straight edge presented to the eye; but, looking down into the trough, no light could be seen beyond, and very slight variations could not be detected there, which could be seen if the bearing surfaces were between the eye and the light.

* Principes d'Hydraulique. Par M. Dubuat. Paris, 1816. Art. 439 and 458.
† Architecture Hydraulique. Par Bélidor. Paris, 1819. Page 342.

It may be that variations of 0.0002 ft. were overlooked, though such were detected at Station No. 5.

To obtain as definite an idea as we may of the precision necessary to obtain accurate results with a piezometer, let the results obtained at the several orifices of the first group be worked up separately. The heights of the piezometers above and below the surface of the stream will be expressed approximately as follows: —

STATION No. 4.	West side, — $0.00004\ U^2$	East side, — $0.00006\ U^2$
STATION No. 8.	West side, + $0.00022\ U^2$	East side, + $0.00006\ U^2$
STATION No. 9.	East side, + $0.00002\ U^2$	

Applying as well as we may the results obtained in the second group of experiments, and assuming the variation in height to be proportional to the angle of inclination with the plane of the side, of the horizontal elements of the surface bounded by the edge of the orifice, it will be seen that an extreme variation from the plane of the side in the length of any of the longer of these elements of 0.0004 ft., 0.0002 ft., 0.0003 ft., 0.0002 ft., and 0.0002 ft., respectively at the several orifices, in the order in which they have been named, will account for the several variations in the height of the piezometric columns above or below the surface of the stream; and a less variation from the plane of the side, in the length of any of the shorter horizontal elements of the circular orifices, would serve to account for them.

It will be observed that the heights by the piezometer whose orifice was 0.334 ft. long horizontally indicated more nearly than those with smaller orifices the actual height of the stream.

From these results, it is evident that it is entirely within the practicable limits of construction to make piezometers that will indicate the true height of the stream, within the practicable limits of observation.

III.

CONTRIBUTIONS FROM THE CHEMICAL LABORATORY OF HARVARD COLLEGE.

RESEARCHES ON THE SUBSTITUTED BENZYL COMPOUNDS.

By C. Loring Jackson and Alfred W. Field.

FOURTH PAPER.

PARACHLORBENZYL COMPOUNDS.

Presented December 12th, 1877.

Parachlorbenzylchloride, $C_6H_4ClCH_2Cl$. In beginning these researches, we had no idea that it would be necessary to investigate this substance, as, since its discovery by Beilstein and Geitner,* it had been prepared and studied by a great number of chemists, and had served as the starting-point for the preparation of all the parachlorbenzyl compounds known. But, on looking into the subject more carefully, we found that it had been made invariably from the product of the chloriring of toluol in the cold, which Hübner and Majert † have proved, by their work on the sulpho-acids, is a mixture of ortho and parachlortoluol; while, more recently, Oscar Emmerling ‡ has shown that the product from oxidizing it with potassic permanganate contains more ortho than parachlorbenzoic acid. The parachlorbenzylchloride of previous chemists, therefore, must have been contaminated with a larger or smaller amount of the ortho compound, which escaped detection, because the method used by them to test the purity of their preparations consisted in oxidizing with potassic dichromate and sulphuric acid, and, as this destroys the ortho modification completely, a pure parachlorbenzoic acid was the only product. This oversight is not surprising when it is borne in mind that the more important of

* Beilstein and Geitner, Zeitschr. der Chem., 1866, p. 307; also p. 17.
† Hübner and Majert, Ber. D. Ch. G. vi. p. 790.
‡ O. Emmerling, Ber. D. Ch. G. viii. p. 880.

these papers appeared in 1866, when the nature of aromatic isomeres was very imperfectly understood.

For the reason given above, we determined to prepare the parachlorbenzylchloride from perfectly pure parachlortoluol, and hoped that it might be a solid, instead of the oily liquid described by our predecessors; indeed, it seemed hard to believe that it could be a liquid, as the parachlortoluol melts at 6½° (Hübner and Majert), and we had already found that the introduction of bromine into the side-chain raised the melting-point to 48½°.

Preparation. Parachlortoluol was made from pure paratoluidine by treatment with hydrochloric acid and potassic nitrite, according to a modification of the method of Hübner and Majert,* described in connection with parachlorbenzylbromide in the first paper † of this series. The 31 grs. that we obtained distilled over completely between 160° and 161°, and froze between 4° and 5° in white plates looking exactly like parabromtoluol, which melted from 7° to 7½°. These results agree essentially with those of Hübner and Majert,* who found the boiling-point 160½°, the freezing-point a little above 0°, and the melting-point 6½°. To convert this into parachlorbenzylchloride, a stream of chlorine was passed into it while it stood in a paraffine-bath heated to 166°: when the increase in weight showed that somewhat more than the calculated amount of chlorine had been taken up (the 27 grs. of parachlortoluol used had become 35 grs. instead of 34.3 grs.), the chlorine was stopped, and the product put in a freezing mixture of ice and salt, where it partially solidified in white needles, which were drained on the filter-pump, and recrystallized from alcohol. The yield was very small, and all attempts to get more from the mother-liquors were fruitless. The following analyses of the substance dried *in vacuo* show that it is the expected parachlorbenzylchloride.

0.6760 gr. of substance gave 1.2930 gr. of CO_2 and 0.2458 gr. of H_2O.‡

0.2755 of substance gave, by Klobukowski's § modification of Emil Kopp's method, 0.4946 gr. AgCl.

---

* Hübner and Majert, Ber. D. Ch. G. vi. p. 794.

† These Proceedings, XII. (N. s. IV.) p. 218.

‡ Combustion of these parachlorbenzyl compounds with plumbic chromate alone was found to yield good results much more easily than the more usual method of combustion in a stream of oxygen, and therefore was used in the analysis of all these substances.

§ Klobukowski, Ber. Dt. C. G. 10, p. 290.

	Calculated for $C_7H_6Cl_2$.	Found.
Carbon	52.17	52.17
Hydrogen	3.73	4.04
Chlorine	44.10	44.41
	100.00	100.62

Properties. White lustrous prisms or needles, often more than 3 cm. long, with an agreeable aromatic odor and most violent action on the mucous membrane and tenderer parts of the skin; melting-point, 29°; so volatile that a crystal exposed to the air disappears in a few hours; sublimes even at ordinary temperatures in needles; it is very little, if at all, soluble in water, but readily in warm, less so in cold, alcohol, very easily in ether, benzole, carbonic disulphide, and glacial acetic acid. That it is a chlorbenzyl compound was proved by boiling it for some time with water, in a flask with a return-cooler, when the parachlorbenzylalcohol and hydrochloric acid were formed. Boiled with a solution of potassic permanganate, it was easily oxidized, giving an acid which melts between 233° and 235° (O. Emmerling gives 234° as the melting-point of parachlorbenzoic acid); this acid boiled with water, in which the orthochlorbenzoic acid is much more soluble than the para, gave a solution which deposited crystals melting also at 233°–235°: as potassic permanganate oxidizes instead of destroying the ortho compounds, this proves that our parachlorbenzylchloride is perfectly free from isomeric impurities.

Having thus proved that the parachlorbenzylchloride used as a starting-point for the preparation of derivatives by Beilstein, Kuhlberg, Neuhof, and others, really did contain the ortho compound, as we had previously inferred, we next proceeded to make some of these derivatives, and redetermine their properties. In this work, the more easily purified parachlorbenzylbromide was used instead of the chloride.

Parachlorbenzylalcohol, $C_6H_4ClCH_2OH$, was made by boiling the bromide (or chloride) with water in a flask with a return-cooler. The formation of hydrobromic (or hydrochloric) acid by this reaction was proved by testing the water, which had become acid, with argentic oxide, when argentic bromide (or chloride) was formed, and the acid reaction disappeared. The alcohol was made also from the acetate by boiling with water: sealing with aqueous ammonia, as recommended by Beilstein and Kuhlberg, being found in this case unnecessary: it was purified by crystallization from boiling water, dried *in vacuo*, and analyzed.

0.4517 gr. of substance gave 0.9754 gr. CO_2 and 0.2175 gr. H_2O.

	Calculated for C_7H_6ClOH.	Found.
Carbon	58.94	58.89
Hydrogen	4.91	5.34

Properties. Beautiful pointed white ribbons usually one or two inches long, with a brilliant pearly lustre and characteristic smell, but no action on the mucous membrane or tenderer parts of the skin; melting-point, 70½° ; sublimes very easily in white needles, and can be purified in this way; evaporates slowly on exposure to the air, and distils in a current of steam; slightly soluble in cold, much more so in hot water, very easily in alcohol, ether, benzole, carbonic disulphide, and glacial acetic acid. It is oxidized by a mixture of potassic dichromate and dilute sulphuric acid, giving parachlorbenzoic acid; melting-point, 233° (234° O. Emmerling).

The chlorbenzylalcohol obtained by Beilstein and Kuhlberg * differs from the above only in melting at 66°.

Parachlorbenzylcyanide. The product of the reaction of alcoholic parachlorbenzylbromide and potassic cyanide, when precipitated by water, was a yellow oil, which showed no signs of solidifying in a mixture of ice and salt: after standing in an open watch-glass for three or more weeks, however, it did deposit crystals when put in a freezing-mixture, but in such small quantity that it was impossible to purify them thoroughly; and it did not seem worth while to spend the large amount of time and material necessary to get enough of them for complete study. The crystals, after sucking out the oil with filter-paper, proved to be good-sized colorless prisms; and, as one specimen of a twinned form like a quatrefoil was observed, there can be no doubt that the substance is analogous to the parabrombenzylcyanide: † its melting point is 29°; and it is easily soluble in alcohol and ether, being left on evaporation of the solvent as an oil which crystallizes when stirred.

The yellow oil from which the crystals were obtained has also the nitrile smell, and is converted, by heating to 100° in a sealed tube with hydrochloric acid, into parachloralphatoluylic acid: it must therefore be either the same substance as the crystals, prevented from solidifying by a small quantity of impurity, or the crystals may be a polymeric form of the oil. The cyanide was mentioned by Neuhof ‡

---

* Beilstein and Kuhlberg, Ann. Chem. Pharm. 147, p. 339.

† These Proceedings, XII. (N. S. IV.) p. 222.

‡ Neuhof, Ann. Chem. Pharm. 147, p. 347.

as a dark oil, made by heating chlorbenzylchloride to 120°–130° in a sealed tube with potassic cyanide and alcohol; but no attempt was made to purify or analyze it. This heating in a sealed tube to 120°–130° is, as seen from the above, unnecessary.

Parachloralphatoluylic Acid, $C_6H_4ClCH_2COOH$, made by heating the nitrile to 100° in a sealed tube with fuming hydrochloric acid, or by boiling it with dilute sulphuric acid in a flask with a return-cooler, was purified by solution in ammonic hydrate, precipitation with sulphuric acid, and recrystallizing from boiling water. Its composition was established by an analysis of the silver salt.

Properties. White needles, often two centimetres long, sometimes thick and pointed, with a pleasant smell; melting-point, 103½°–104°; sublimes easily in little plates, and can be distilled, although not quickly, in a current of steam; somewhat soluble in cold, much more so in hot water, freely in alcohol, ether, benzole, carbonic disulphide, and glacial acetic acid. Aqueous ammonia dissolves it readily, but the ammonic salt is decomposed, at least in part, by evaporation the acid being set free.

A chloralphatoluylic acid has been already described as the para compound by Neuhof,* who made it, however, from chlorbenzylchloride; the melting-point was 60°, and it separated from its salts as an oil which soon solidified, otherwise it resembled our acid, except that it seems to have been much more soluble in water. Later, Radziszewski † made a similar acid, melting at 68° by chloriring alphatoluylic acid.

Argentic Parachloralphatoluylate, $C_6H_4ClCH_2COOAg$, fell as a white, curdy precipitate, upon adding argentic nitrate to a neutral solution of the ammonic salt of the acid. It was washed with water, dried at 100°, and analyzed.

0.3410 gr. of substance gave, precipitated from a nitric acid solution, with hydrochloric acid, 0.1788 gr. of AgCl.

	Calculated for $C_8H_6ClO_2Ag$.	Found.
Silver	38.91	39.44

Properties. A white, curdy mass, consisting of clumps of silky microscopic needles, which blackens rapidly in direct sunlight, but only very slowly in diffused daylight; very slightly soluble in boiling water, almost insoluble in cold, freely soluble in dilute nitric acid and ammonic hydrate.

---

* Neuhof, Ann. Chem. Pharm. 147, p. 347.

† Radziszewski, Ber. D. Ch. G. ii. p. 207.

Neuhof obtained a similar salt, but describes it as more soluble in water than ours.

We did not succeed in getting a pure, well-defined *calcic salt*, although we tried to do so several times. By adding lime-water to the acid till the reaction was alkaline, removing the excess of lime by carbonic dioxide, and allowing the solution to evaporate spontaneously, arborescent groups of white needles were obtained. These lost 9.84 per cent when dried at 100°; 2 molecules of crystal water would give 8.68 per cent; 2½ molecules, 10.61 per cent; the loss, therefore, does not correspond to any probable amount of water of crystallization, and it seemed likely that something beside water was given off, as there was a slight sublimate on the upper watch-glass, and the substance had become somewhat brown, with a semifused look very unlike its original appearance. It, however, contained 10.36 per cent of calcium, and may therefore have been the anhydrous salt which needs 10.55 per cent. Other experiments under different conditions gave no better results, and we therefore decided that the salt was not important enough to repay a thorough study, which would use up a great deal of time.

The *baric salt* was even less well defined than the calcic: it was prepared in the same way, and appeared on evaporation of its solution over sulphuric acid as a colorless varnish, part of which changed on stirring into a radiated crystalline mass. This became white and opaque when treated with cold water, and when boiled with water gave an acid reaction and the smell of the acid. If the solution was evaporated on the water-bath instead of over sulphuric acid, a sticky gum was left. Neuhof's baric salt was similar to ours, and gave him an amount of barium corresponding to an acid salt. His calcic salt, on the other hand, contained one molecule of water, which it lost at 100°.

A solution of the acid in ammonic hydrate, from which the excess of ammonia has been driven off on the water-bath, gives reactions with salts of the various metals similar to those of the corresponding brom-acid.* The bluish-green flocks with *cupric sulphate*, yellowish-brown with *ferric chloride*, and white with *plumbic acetate* or *mercurous nitrate* are especially characteristic.

Parachlorbenzylsulphocyanate, $C_6H_4ClCH_2SCN$, made by boiling the bromide with an alcoholic solution of potassic sulphocyanate, was purified by freezing with snow and salt, sucking out the oil with filter-

* These Proceedings, XII. (N. S. IV.) p. 225.

paper, and recrystallization from alcohol with the help of a freezing-mixture. It was dried *in vacuo* and analyzed.

0.1569 grs. substance gave 0.1985 grs. $BaSO_4$.

	Calculated for C_7H_6ClSCN.	Found.
Sulphur	17.43	17.38

Properties. White, flattened needles, often over an inch long, with a strong, disagreeable smell; melting-point, 17°; does not distil with steam, but seems to be slowly decomposed by it, a few brown drops with a smell like that of benzaldehyd passing over; mixes with alcohol, ether, benzole, carbonic disulphide, and glacial acetic acid, but not with water.

This substance has not been made heretofore: it resembles the corresponding bromine compound very closely in every thing but melting-point.

Parachlorbenzylamines.

These substances have been studied already by Berlin,* who prepared them by heating the chlorbenzylchloride with alcoholic ammonia for one week in the steam-bath. The product was worked up by a needlessly complex process, consisting, when stripped of its unnecessary steps, in separating one portion of the bases by conversion into their chlorides and crystallizing from alcohol, while in the remainder the tertiary amine was destroyed by distillation with bromine and water, and the bromides of the remaining amines separated by crystallization. The properties of the tertiary and primary amines, as described by him, are in no way peculiar; but he obtained four isomeric forms of the secondary amine, which were themselves undistinguishable yellow oils, but differed in the melting-points of their salts, as shown in the following table:—

Name of Salt.	Melting Points.			
	α	β	γ	δ
Chloride	288°–289°	225°–228°	218°–220°	221°–222°
Bromide. . . .	283°–290°	224°	210°–212°	198°–199°
Iodide	. . . .	215°	187°	216°–218°
Nitrate	. . . .	204°–205°	198°	177°–179°

These salts also differed in solubility, the α modification being the least, the δ the most soluble: they were separated by crystallization

* Berlin, Ann. Chem. Pharm. 151, p. 137.

of the bromides from water. These observations rendered a repetition of Berlin's work very interesting; but we did not follow the process given by him, as we have found a much more easy and simple method for the separation of the bases. Alcoholic ammonia acted very quickly, even in the cold, on parachlorbenzylbromide: the product from this or from the action in a sealed tube at 100° consisted of crystals either of the bromide of the tertiary amine or of the base itself, and of an alcoholic solution, which, filtered off and evaporated on the steam-bath, yielded the bromides of ammonium and of the primary and secondary amines with some free tertiary amine. This residue, after washing with water to remove the bromides of ammonium and the primary amine, was repeatedly crystallized from hot alcohol, until it was divided into slightly soluble scales of secondary bromide and needles of the free tertiary amine readily soluble in boiling alcohol.

Triparachlorbenzylamine, $(C_6H_4ClCH_2)_3N$, was freed from a trace of bromide by crystallizing from ether, dried *in vacuo*, and analyzed.

0.7096 grs. of substance gave 1.6780 grs. CO_2, and 0.3300 grs. H_2O.

	Calculated for $(C_7H_6Cl)_3N$.	Found.
Carbon	64.78	64.49
Hydrogen	4.61	5.16

Properties. Bunches of white needles, when crystallized from alcohol; from ether it separates as an oil, which solidifies after some time in flattened prisms; it is also deposited from the action of cold alcoholic ammonia on parachlorbenzylbromide in short, thick, well-formed crystals, with rhombic faces; melting-point, 78½°; insoluble in water, very slightly soluble in cold, freely in hot alcohol, and in ether, benzole, and carbonic disulphide, less so in glacial acetic acid.

The *chloride* was obtained in an impure state when an alcoholic solution of the base was heated with strong hydrochloric acid; after standing 24 hours, the solution was allowed to evaporate spontaneously, when balls of radiated needles were left which melted at about 196°, were soluble in alcohol, ether, and glacial acetic acid, slightly in water, and insoluble, or nearly so, in carbonic disulphide and benzole; the alcoholic solution left a viscous mass, which changed into needles slowly. After drying *in vacuo*, it lost, in the steam-bath, an amount equal to less than one molecule of water; but its melting-point was unaltered, and, as it yielded crystals of the free amine on repeated treatment with alcohol, it does not follow that the loss was nothing but water. We could find no satisfactory method of purifying this, or of making a purer substance. The *bromide* obtained in the prepa-

ration of the amines crystallizes in scales like those of the bromide of the secondary amine soon to be described, but less soluble in alcohol.

Triparachlorbenzylamine Chlorplatinate, $[(C_6H_4ClCH_2)_3NH]_2PtCl_6$, was made by adding aqueous platinic chloride to an ethereal solution of the base, and washing with water, alcohol, and ether; dried at 100°, it gave the following results on analysis: —

I. 0.2380 grs. substance gave 0.0405 grs. platinum.

II. 0.2796 grs. substance gave 0.0471 grs. platinum.

	Calculated for $[(C_7H_6Cl)_3NH]_2PtCl_6$.	Found. I.	Found. II.
Platinum	16.54	17.01	16.84

Properties. Pale orange microscopic irregular plates, almost insoluble in water, alcohol, and ether.

It is worthy of especial note that Berlin's tertiary chlorbenzylamine melted at 88°–89°, as this is the only case in which we have found the melting-point of the pure substance lower than that of the impure. His chloride melting-point, 170°–175°, crystallized in well-formed rhombohedra with two molecules of water, which it lost *in vacuo*. Our (impure) salt differed from his not only in appearance and melting-point, but also in losing nothing *in vacuo;* and we have never observed any rhombohedra like those described by him, although we have tried very often and under various conditions to obtain them.

Diparachlorbenzylamine, $(C_6H_4ClCH_2)_2NH$. The bromide of this base, separated from the other amines as described above, and purified by repeated boiling with alcohol, was decomposed with aqueous sodic hydrate; the oil thus obtained solidified on stirring, especially if it was touched with a crystal of the substance.

Properties. White radiating bladed crystals; melting-point, 29°; insoluble in water, soluble in alcohol and glacial acetic acid, freely soluble in ether, benzole, and carbonic disulphide.

The *chloride* fell as a white precipitate on adding hydrochloric acid to an alcoholic solution of the base; microscopic rhombic and prismatic plates apparently monoclinic, slightly soluble in water, alcohol, and glacial acetic acid, insoluble in ether and carbonic disulphide; melting-point, 288°.

Diparachlorbenzylamine Chlorplatinate, $[(C_6H_4ClCH_2)_2NH_2]_2PtCl_6$, made by adding aqueous platinic chloride to the alcoholic solution of the base, and purified by washing with water, was dried at 100°, and analyzed.

0.2389 grs. substance gave 0.0496 grs. platinum.

	Calculated for $[(C_7H_6Cl)_2NH_2]_2PtCl_6$.	Found.
Platinum	20.90	20.76

Properties. Pale yellow scales (deeper in color than the corresponding salt of the tertiary amine), slightly soluble in boiling water, almost insoluble in cold water and alcohol.

The *bromide* of the base was obtained during the preparation of the amines in white scales very slightly soluble in water or alcohol, insoluble in ether, easily decomposed by aqueous sodic hydrate, and melting with decomposition between 280° and 290°.

The salts just described are identical with those of the α modification of Berlin's secondary chlorbenzylamine; and, as we could find no trace of any other modifications, there can be but little doubt that the β, γ, and δ forms of Berlin consisted of mixtures of para- and ortho-compounds, in varying proportions, and this view is still further supported by the fact that the melting-points of these so-called isomeres are very near together, those of the chlorides in fact all lying within ten degrees.

Monoparachlorbenzylamine, $C_6H_4ClCH_2NH_2$, precipitated from the aqueous solution of its bromide with sodic hydrate and distilled with steam forms a colorless oil nearly, if not completely, insoluble in water, but soluble in ether; on exposure to the air it is converted, almost at once, into a white soluble crystalline carbonate; if therefore care is not taken to exclude carbonic anhydride, small quantities of the amine seem to dissolve easily in water.

The *carbonate* was made by exposing the free base to carbonic anhydride or even to the air, and was always left when an ether extract containing the base was allowed to evaporate spontaneously. Crystallized from water, it forms white plates often of considerable size, from alcohol needles; melting-point, 114°–115°; it dissolves slowly in cold, quickly and freely in hot water and alcohol; sodic hydrate sets free the oily amine.

The *chloride* made by dissolving the carbonate in hydrochloric acid crystallizes in long, narrow white plates, soluble in water and alcohol, sparingly soluble in glacial acetic acid, and essentially insoluble in ether, benzole, and carbonic disulphide; melting-point, 239°–241°.

Monoparachlorbenzylamine Chlorplatinate, $(C_6H_4ClCH_2NH_3)_2PtCl_6$, made by mixing a solution of the chloride of the base with platinic chloride, purified by washing with a mixture of alcohol and ether, and dried at 100°, gave the following result:—

0.3067 grs. substance gave 0.0866 grs. platinum.

	Calculated for $(C_7H_6ClNH_3)_2PtCl_6$.	Found.
Platinum	28.39	28.23

Properties. Bright yellow branching plates or needles, arranged in round woolly groups when crystallized from water, in which and alcohol it is decidedly soluble.

The *bromide* of the base formed in the preparation of the amines resembles the chloride in appearance and solubility, but is somewhat less soluble in cold water, and melts with decomposition between 225° and 230°.

The foregoing results differ from those obtained by Berlin only in the melting-point of the chloride, which he found 197°; he gives no melting-points for the carbonate and bromide.

To make it easier to compare the new melting-points with those in use heretofore, we have collected them in the following table; the second column of which gives the melting-points of the pure substances made by us, and the third the melting-points determined by the chemists mentioned in the fourth column.

Name of Substance.	True Melting-point	Old Melting-point	Authority for Old Melting-point.
Parachlorbenzylchloride . . .	29°	Liquid.	Beilstein and Geitner.
Parachlorbenzylbromide . . .	48½°		
Parachlorbenzylalcohol . . .	70½°	66°	Beilstein and Kuhlberg.
Parachlorbenzylcyanide . . .	29° (?)	Liquid.	Neuhof.
Parachloralphatoluylic Acid .	103¾–104°	60°	Neuhof.
		68°	Radziszewski.
Parachlorbenzylsulphocyanate	17°		
Primary Amine	Liquid.	Liquid.	Berlin.
" " Chloride . . .	239°–241°	197°	"
" " Bromide . . .	225°–230°		
" " Carbonate . .	114°–115°		
Secondary Amine.	29°	Liquid.	Berlin.
" " Chloride . .	288°	288°–289°	"
" " Bromide . .	280°–290°	283°–290°	"
Tertiary Amine	78½°	88°–89°	"
" " Chloride. . .	196° (?)	170°–175°	"

The revision of the parachlorbenzyl compounds will be continued in this laboratory; in fact, the aldehyde and some of the sulpho-derivatives have been already made and partially studied by Mr. J. Fleming White, whose work will form the subject of a later paper of this series.

IV.

THE DEVELOPMENT OF LEPIDOSTEUS.

By Alexander Agassiz.

Presented Oct. 8, 1878.

PART I.

It has been my good fortune this spring to succeed in hatching Lepidosteus from the egg, and in raising the young until they showed externally, at least, the principal structural features of the adult.

Like many other American naturalists, I had for many years been on the lookout for the breeding-places of our Lepidosteus and Amia; but although it was generally known that during the last part of May they appeared in large numbers in the Potomac, as well as in many Western rivers, and also in parts of the great lakes, no one had been fortunate enough to catch these fish while spawning. It was therefore with great expectations that I sent Mr. S. W. Garman to Ogdensburgh, N. Y., when Mr. S. S. Blodgett informed me that the garpike usually appeared on the 20th of May for the purpose of spawning. Mr. Blodgett did all in his power to make the expedition a success; and he has not only my thanks, but will have those of all naturalists, for the aid he has given so effectually in obtaining this ichthyological prize.

The following notes by Mr. Garman describe the method of spawning: —

"Black Lake is well stocked with bill fish. When they appear, they are said to come in countless numbers. This is only for a few days in the spring, in the spawning season, between the 15th of May and the 8th of June. During the balance of the season, they are seldom seen. They remain in the deeper parts of the lake, away from the shore, and, probably, are more or less nocturnal in habits. Out of season, an occasional one is caught on a hook baited with a minnow. Commencing with the 20th of April, until the 14th of May we were unable to find the fish, or to find persons who had seen them during

this time. Then a fisherman reported having seen one rise to the surface. Later, others were seen. On the afternoon of the 18th, a few were found on the *points*, depositing the spawn. The temperature at the time was 68° — 69° on the shoals, while out in the lake the mercury stood at 62° — 63°. The '*points*' on which the eggs were laid were of naked granite, which had been broken by the frost and heat into angular blocks of three to eight inches in diameter. The blocks were tumbled upon each other like loose heaps of brickbats, and upon and between them the eggs were dropped. The *points* are the extremities of small capes that make out into the lake. The eggs were laid in water varying in depth from two to fourteen inches. At the time of approaching the shoals, the fish might be seen to rise quite often to the surface to take air. This they did by thrusting the bill out of the water as far as the corners of the mouth, which was then opened widely and closed with a snap. After taking the air, they seemed more able to remain at the surface. Out in the lake they are very timid, but once buried upon the shoals they become quite reckless as to what is going on about them. A few moments after being driven off, one or more of the males would return as if scouting. If frightened, he would retire for some time; then another scout would appear. If all promised well, the females, with the attendant males, would come back. Each female was accompanied by from one to four males. Most often a male rested against each side, with their bills reaching up toward the back of her head. Closely crowded together, the little party would pass back and forth over the rocky bed they had selected, sometimes passing the same spot half a dozen times without dropping an egg, then suddenly would indulge in an orgasm; and, lashing and plashing the water in all directions with their convulsive movements, would scatter at the same instant the eggs and the sperm. This ended, another season of moving slowly back and forth was observed, to be in turn followed by another of excitement. The eggs were excessively sticky. To whatever they happened to touch they stuck, and so tenaciously that it was next to impossible to release them without tearing away a portion of their envelopes. It is doubtful whether the eggs would hatch if removed. As far as could be seen at the time, upon or under the rocks to which the eggs were fastened, there was an utter absence of any thing that might serve as food for the young fishes.

"Other fishes, bull heads, &c., are said to follow the bill fish to eat the spawn. It may be so. It was not verified. Certainly the points under observation were unmolested. During the afternoon of the

18th of May, a few eggs were scattered on several of the beds. On the 19th, there were more. With the spear and the snare, several dozens of both sexes of the fish were taken. Taking one out did not seem greatly to startle the others. They returned very soon. The males are much smaller than the average size of the females; and, judging from those taken, would seem to have as adults greater uniformity in size. The largest taken was a female, of four feet one inch and a half in length. Others of two feet six inches contained ripe ova. With the 19th of May, all disappeared, and for a time — the weather meanwhile being cold and stormy — there were no signs of their continued existence to be met with. Nearly two weeks later, on the 31st of May, as stated by Mr. Henry J. Perry, they again came up, not in small detachments on scattered points as before, but in multitudes, on every shoal at all according with their ideas of spawning-beds. They remained but two days. During the summer it happens now and then that one is seen to come up for his mouthful of air; beyond this there will be nothing to suggest the ravenous masses hidden by the darkness of the waters."

To Mr. Garman I am greatly indebted for the care with which he transported a quantity of garpike eggs contained in two pails which had to be carried by hand from Ogdensburgh to Cambridge, and for the arrangements made with Mr. Perry for collecting a series of eggs and of young fishes in all stages from the time of spawning until the end of July.

The present paper is, of course, merely a preliminary account, and I hope to give on another occasion a full description of the early stages of the egg, as well as a more detailed description of the changes the young undergo. Of the eggs brought to Cambridge, only thirty hatched. In my anxiety lest this attempt should fail, I did not dare to examine any of the fresh eggs; and from an external examination little or nothing of the early stages of segmentation and of the development could be traced on account of the opacity of the envelope of the egg. Not one of the eggs artificially fecundated was hatched, and only a few of those laid on the angular blocks (mentioned by Mr. Garman) lived to complete their development. The eggs were all attacked by mould, and decomposed rapidly in spite of the most watchful care. The few which did hatch, however, fully rewarded my efforts and fulfilled my anticipations. The young fish were quite hardy and flourished admirably. Of the thirty hatched in the latter part of May, no less than twenty-eight lived till the middle of July. They were exceedingly hardy, and, had it been possible to

feed them on minute fresh-water Entomostraca, I have no doubt they would have continued in excellent condition. During the whole time of the resorption of the yolk-bag, not a single individual was lost. It was only subsequently, when they had been fed for a while on liver, that they showed symptoms of poor condition; and finally they refused to eat it and languished for a few days, although at first they had eaten it apparently with great relish.

The eggs were laid on the 20th of May; when they reached Cambridge, they were still semi-transparent, the yellowish-green sticky outer envelope measuring about 5^{mm} in diameter; the yolk-mass, of a whitish-blue color, was 3^{mm}. In their general appearance, the eggs resembled those of toads. They were attached to the stones just as they dropped from the females, in groups irregularly arranged or isolated.

On the 28th of May, the first young Lepidosteus was hatched (Plate I. fig. 1). The young fish possessed a gigantic yolk-bag, and the posterior part of the body presented nothing specially different from the general appearance of a Teleostean embryo, with the exception of the great size of the chorda. The anterior part, however, was most remarkable; and at first, on seeing the head of this young Lepidosteus, with its huge mouth cavity extending nearly to the gill-opening, and surmounted by a hoof-shaped depression edged with a row of protuberances acting as suckers (Plate I. fig. 3), I could not help comparing this remarkable structure, so utterly unlike any thing in Fishes or Ganoids, to the Cyclostomes, with which it has a striking analogy. This organ is also used by Lepidosteus as a sucker, and the moment the young fish is hatched he attaches himself to the sides of the dish, and there remains hanging immovable; so firmly attached, indeed, that it requires considerable commotion in the water to make him loose his hold. Aerating the water by pouring it from a height did not always produce sufficient disturbance to loosen the young fishes. The eye, in this stage, is rather less advanced than in corresponding stages in bony fishes; the brain is also comparatively smaller, the otolith ellipsoidal, placed obliquely in the rear above the gill-opening. This is at first a mere small elliptical opening, which subsequently becomes heart-shaped (Plate I. fig. 11) with the development of the gill-arches, one of which is formed by the anterior part of the gill-opening, while two smaller ones are formed behind it (Plate I. fig. 6) much as in Sharks, except that we have a gill-cover in Lepidosteus as in bony fishes, which completely hides the gill-arches from view, when seen in profile. It is only when seen obliquely from

above that the gills can be seen behind the operculum, or when they are separated from the body in breathing (Plate II. fig. 16). Usually the gill-cover is pressed closely against the sides of the body, but in breathing an opening is seen (Plate IV. fig. 37) through which water is constantly passing, a strong current being made by the rapid motion of the pectorals, against the base of which the extremity of the gill-cover is closely pressed (Plate IV. fig. 42). The large yolk-bag is opaque, of a bluish-gray color. The body of the young Lepidosteus is quite colorless and transparent. The embryonic fin is narrow, the dorsal part commencing above the posterior end of the yolk-bag; the tail is slightly rounded, the anal opening nearer the extremity of the tail than the bag. The intestine is narrow, and the embryonic fin extending from the vent to the yolk-bag is quite narrow. In a somewhat more advanced stage (Plate I. fig. 3), — hatched a few hours earlier, — the upper edge of the yolk-bag is covered with black pigment cells, and minute black pigment cells appear on the surface of the alimentary canal. There are no traces of embryonic fin-rays either in this stage or the one preceding; the structure of the embryonic fin is as in bony fishes — previous to the appearance of these embryonic fin-rays — finely granular. Seen in profile, the yolk-bag is ovoid; as seen from above, it is flattened (Plate I. fig. 1), rectangular in front, with rounded corners, tapering to a rounded point towards the posterior extremity, with re-entering sides (Pl. I. fig. 7).

The head seen from above is rounded anteriorly, fringed by the row of suckers which form a connected, thickened margin; the eyes scarcely project beyond the general outline of the head; the gill-covers are small lobes immediately behind the eyes. The brain occupies but a comparatively small part of the head; the olfactory lobes are greatly developed, and elongated much as in Sharks and Skates, the posterior extremity of the brain rising obliquely towards the back and leaving a considerable distance between the base of the brain and the termination of the chorda, which ends between the otoliths (Plate I. figs. 6–11).

The second day after hatching, we can detect (Plate I. fig. 11) the first trace of an upward curve to the extremity of the tail. Up to this time, the chorda is straight, as is the embryo of any newly hatched bony fish; the yolk-bag has also greatly decreased in size; the head makes a less sharp angle with the longitudinal axis; the snout formed by the sucking-disk projects well beyond the outline of the opening of the mouth; the gill-opening is heart-shaped, and the heart can distinctly be seen to beat at the junction of the yolk-bag

with the lower part of the mouth cavity; the embryonic fin has broadened, and extends further along the back towards the head; the muscular bands surrounding the chorda are far better defined, and a few black pigment spots have also made their appearance at the base of the anal fin; the eye has become more distinct, and the nostrils are seen as elliptical pits close to the eye as in the earlier stage.

On the third day, the young Lepidosteus, when seen in profile, has a triangular yolk-bag (Plate II. fig. 13), greatly reduced in size from the previous stage; the whole body is covered with minute black pigment cells, more numerous towards the head and along the dorsal side; the gill-covers are now large rectangular flaps (see also Plate II. fig. 12), and we find in this stage the first trace of the pectorals. These appear at first at a distance from the body on the upper surface of the yolk-bag (Plate II. fig. 12) as slight curlings of what we may call a lateral fold, indicated by a spiral line on the upper part of the yolk-bag. Seen in profile (Plate II. fig. 13), they stand up vertically, forming slight protuberances above the general surface of the yolk-bag. The eyes are more prominent; the whole snout has become more elongated than in previous stages; and the sucking-disk is more prominent than in younger stages, — the individual suckers projecting frequently far beyond the general outline of the edge of the sucker, when the young fish holds to any surface to which it may firmly have attached itself. The outline of the tail, or of the embryonic fins, has not altered from the preceding stage.

The young Garpikes would find it most inconvenient to move about with the huge yolk-bag with which they are provided; and although when disturbed they are powerful swimmers, propelling themselves much after the manner of tadpoles, by vigorous strokes of the tail, yet they remain until much later in life nearly constantly attached to the sides or bottom of the jars in which they are kept; and, if disturbed, will, after swimming round rapidly a few moments, hasten to attach themselves again to some suitable surface, where they remain hanging motionless during the greater part of the time till the yolk-bag has been completely resorbed. Their hold on the sides of the jar was so strong that they would remain suspended after the water had been lowered below the level to which they were attached.

Two days later, the yolk-bag has become still further reduced, especially under the gill-covers (Plate II. fig. 14); the trend of the head also makes a larger angle with the axis; the eyes have become more prominent; the gill-covers have greatly lengthened (Plate II. fig. 15),

and the pectorals have increased in size. The whole body is more thickly covered by black pigment cells: they are most numerous near the region of the head, along the dorsal line, and over the intestines and the upper part of the yolk-bag, making a strong contrast to its yellowish-gray color underneath. The curvature of the tail has increased, and four patches of pigment spots have appeared (Plate II. fig. 14). These are the first traces of the permanent fins, — the dorsal, the caudal, and anal, — the last spot on the dorsal side of the tail forming the spot of the temporary caudal lobe. The gill-arches in this stage (Plate II. fig. 16) are thin, short, club-shaped appendages, seen on certain portions behind the gill-covers.

The great development taken by the sucking-disk is best shown in a view from the lower side. The cavity of the mouth is seen (Plate II. fig. 17) to occupy the greater part of the lower side, between the sucker and the base of the yolk-bag, where the heart is placed. Five or six days afterwards, the cavity of the mouth has become reduced to a small (Plate II. fig. 18) trapezoidal opening; the gill-covers nearly meet on the lower side, near the median line; and in this stage the individual suckers of the sucking-disk are capable of great expansion, projecting, after the young fish has remained attached for a time, far beyond the general outline of the anterior part of the head. When seen in profile (Plate III. fig. 19), the outline of the head has assumed a most peculiar appearance, having certainly no resemblance whatever to the shape of the head in the adult. The yolk-bag has become much reduced in size; the pectorals have now assumed the characteristic Crossopterygian features; the eye is quite prominent; the lower jaw projects slightly beyond the former level of the mouth cavity; and there is also a short upper jaw, terminating in the huge swollen snout, covered with warts, forming the powerful sucking-disk. The gill-cover is still more elongated than in previous stages, and there are short branches to the primary gill-arches. The whole body is now thickly covered with black pigment cells. These cells are, however, still most numerous above the eye, toward the dorsal region, along the upper part of the yolk-bag, where they are so closely packed as to form a dense black band, which is continued on the lower side of the chorda to the extremity of the tail. The black spots of the primary fins have expanded to form definitely shaped patches indicating the growth of the permanent fins, of which they are the rudiments. The extremity of the tail has a more marked heterocercal character, and both above and below the tail carries a large white patch completely surrounded by the darker pigment-cells. The fleshy lobe of the pec-

torals is bluish, as well as the outer edge of the gill-cover. We find also in this stage the first trace of the brilliant white pigment-spots which become the enamelled lines and spots so characteristic of somewhat older stages. In these young, they are found mainly on the sides of the gill-cover and along the line of the chorda on the anterior part of the body.

The next changes are mainly in the lengthening of the snout; the increase in length both of the lower and upper jaw (Plate III. fig. 23); the concentration of the suckers of the sucking-disk (Plate III. figs. 22, 24); and the adoption of the general coloring of somewhat older fish. The lobe of the pectoral has become specially prominent (Plate III. fig. 21), and the outline of the fins is now indicated by a fine milky granulation. Seen from above (Plate III. fig. 20), the gill-cover is seen to leave a large circular opening leading to the gill-arches, into which a current of water is constantly passing, by the lateral expansion and contraction of the gill-cover; the outer extremity of the gill-cover covers the base of the pectorals (Plate III. fig. 26). In a somewhat older stage, the snout has become more elongated (Plate III. fig. 29), the suckers more concentrated, and the disproportionate size of the terminal sucking-disk is reduced; the head, when seen from above, becoming slightly elongated and pointed.

In the next stage, when the young Lepidosteus is a little over three weeks old (Plate III. fig. 30), the young has assumed a more fish-like form; the sucking snout is now reduced to a swelling of the extremity of the elongated upper jaw; the lower jaw has also greatly lengthened; the fleshy part of the pectoral has developed out of proportion to the base; the yolk-bag has disappeared; the gill-cover extends, when pressed against the sides (Plate III. fig. 31), well up along the base of the pectorals; they are now kept in constant rapid motion, so that the fleshy edge is invisible, and the vibration seems almost involuntary, producing a constant current round the opening leading into the cavity of the gills. The latter are seen now to branch quite extensively. The extremity of the tail also has the same rapid vibratile motion which characterizes the pectorals. Professor Agassiz had already noticed this rapid involuntary movement in the temporary caudal lobe of a young Lepidosteus about eight inches in length.

In the stages intervening between Plate III. fig. 19, and Plate III. fig. 30, the young Lepidosteus frequently swim about, and become readily separated from their point of attachment. In the stage of Plate III. fig. 30, they remain often perfectly quiet, close to the sur-

face of the water; but, when disturbed, move very rapidly about through the water. In this stage, we can notice the first trace of the ventrals, at the anterior part of the ventral embryonic fold. They appear first as minute swellings on each side of this fold, and they consist of a central shaft with a fleshy fringe like the pectorals. Seen from above (Plate III. fig. 32), the head has become elongated, the sucking-disk is reduced to a single row of small suckers, and we now begin to see what becomes of this organ. The fleshy globular termination of the upper jaw of the adult Lepidosteus is the remnant of this embryonic sucking-disk. The coloring of the young fish is becoming more and more like that of the adult; the dorsal region is mottled with broad irregular patches of brown; a strong black line extends from behind the eye, on the lower side of the median line, to the extremity of the tail. The young already have also the peculiar habit of the adult of coming to the surface to swallow air. When they go through the process under water of discharging air again, they open their jaws wide, and spread their gill-cover, and swallow as if they were choking, making violent efforts, until a minute bubble of air has become liberated, when they remain quiet again. The resemblance to a Sturgeon in the general appearance of this stage of the young Lepidosteus (Plate III. fig. 30) is quite marked.

The growth of the young Lepidosteus is very rapid. Hatched the 28th of May, they had on the 14th of June attained a length of three-quarters of an inch (Plate III. fig. 33). The snout has become greatly elongated; and the upper jaw shows plainly that the sucking-disk is to become the fleshy accretion at the extremity of the snout. The embryonic fin-fold has become slightly indented, indicating the positions of the future dorsal and anal fins. The ventrals have increased somewhat in size. In this stage, we see the first trace of the permanent fin-rays, of the dorsal, caudal, and anal fins. There are also most delicate embryonic fin-rays, just as we find them in bony fishes at corresponding stages. The fringe of the pectorals is incessantly in rapid vibration, as well as the tip of the tail, except when the fish is at rest near the surface of the water. The tail does not necessarily vibrate with the pectorals: either may be in motion without affecting the other. The teeth make their appearance in this stage, and there are a few fin-rays in the fringe of the pectorals.

Seen from above, the pectorals are usually carried at right angles to the body when in rapid motion (Plate IV. fig. 34). Our young Lepidosteus has now reached a stage (Plate IV. fig. 36) very similar to that first described by Professor Wilder. The head, when seen from

above, shows the sucking-disks reduced to a couple of rows of independent suckers, but the young Lepidosteus no longer attach themselves by it. They have assumed the habits of the adult, rising slowly near the surface, where they frequently remain almost motionless for a long time, merely keeping the pectorals and the tip of the tail in rapid vibration. When they wish to swim about, they strike out vigorously with their tail-fin laterally.

When in a natural attitude, they float with the body curved, the back behind the head flush with the surface, the head nearly horizontal, and the tail curved down (Plate IV. fig. 39, Plate V.).

By the 22d of June, the anterior part of the head had elongated, and the indentations of the embryonic fin-fold marking the future fins are deeper; but the embryonic caudal is still by far the more prominent of the two caudals, although the fin-rays of the permanent caudal are well laid out, and its position has become more terminal than in previous stages (Plate IV. fig. 38).

The external changes undergone by the young Lepidosteus, until the last one of them hatched at Cambridge died, were limited, in the anterior part of the body, to the greater elongation of the jaws; the increase in size and number of the teeth (Plate IV. fig. 41); the growth of ventrals, which resemble in their structure that of the pectorals (Plate IV. fig. 41 *a*); and, in the posterior part of the body, to the better definition of the shape and position of the dorsal, anal, and caudal, as well as the great apparent increase in the length of the temporary caudal filament, from the gradual resorption of the posterior embryonic fin-fold. The head of the young Lepidosteus now shows no further trace of the sucking-disk beyond the fleshy swollen termination of the upper jaw.

There are in this stage five gill-arches carrying short lateral branches (Plate IV. fig. 43). Seen from below, the gill-covers unite on the median line, immediately at the base of the lower jaw.

The largest specimen grew to a length of $\frac{16}{18}$ of an inch, and its coloring (Plate V.) did not differ from that of larger young specimens denoted by Professor Agassiz, which had already attained a length of eight inches.

In conclusion, we may say, as a result of the above observations on the external development of the Lepidosteus, that, notwithstanding its similarity to Sturgeons in certain stages of its growth, notwithstanding its affinity with Sharks and Skates, by the formation of the pectorals from a lateral fold, as well as by the mode of growth of the gill-opening and the gill-arches, the Lepidosteus is, spite of all this, not

so far removed from the bony fishes as has been supposed. On the contrary, it approaches them not only by the development of the general features characterizing the posterior extremity, by the mode of formation of the unpaired fins from the embryonic fin-fold, by the mode of formation of the fin-rays, and also by that of the ventrals. The pigment cells, so well developed in their young stages, before the appearance of scales, are similar to those of bony fishes, with the exception that we have in addition, in early stages, cells of a white silvery lustre, which are undoubtedly the first trace of the enamel to form the armor of the "Garpike."

EXPLANATION OF THE PLATES.

PLATE I.

Fig. 1. Young Lepidosteus just escaped from the egg, measuring 8mm. in length.
„ 2. Tail of specimen slightly older.
„ 3. Tail of specimen somewhat older than fig. 2.
„ 4. Head of young Lepidosteus just hatched, showing the mouth cavity and the disk.
„ 4a. The same, seen somewhat more in profile.
„ 5. Another specimen, with the head thrown back, looking into the mouth cavity.
„ 6. Head seen in profile, showing the gill-arches, the heart, the auditory capsule, and the muscular segment covering the chorda.
„ 7. In stage of fig. 1 (hatched the same day), seen from above.
„ 8. Head of specimen somewhat older than fig. 7.
„ 9. Gill-arches of specimen in stage of fig. 7.
„ 10. Shows position of heart in middle of anterior part of the yolk-bag.
„ 11. Young Lepidosteus at the end of the first day.

PLATE II.

„ 12. Young Lepidosteus, seen from above, three days old.
„ 13. Same, seen in profile.
„ 14. Profile of young on the fifth day after hatching.
„ 15. Same as fig. 14, seen from above.
„ 16. Gill-openings of same specimen.
„ 17. Same age as fig. 14, seen from the lower side.
„ 18. Anterior part of young Lepidosteus, ten days old, seen from below.

PLATE III.

Fig. 19. Profile of young specimen eleven days old.
„ 20. Head of same, seen from above.
„ 21. Magnified pectoral of same.
„ 22. End-view of sucking-disk of same.
„ 23. Profile of head of specimen somewhat more advanced.
„ 24. Profile of sucking-disk of another specimen about in the same stage of development.
„ 25. Tail of specimen of same age as fig. 19, but somewhat more advanced.
„ 26. Gill-opening of same, seen from above.
Figs. 27, 28. Profiles to show protuberances of sucking-disk of head in different degrees of expansion, one day older than preceding stage.
Fig. 29. Profile of head of specimen thirteen days old.
„ 30. Profile of young Lepidosteus $20^{mm.}$ long, nineteen days old.
„ 31. Head of same, seen from above.
„ 32. Tail of specimen seventeen days old, but evidently more advanced than the preceding figure (30).
„ 33. Head of same (fig. 32), seen in profile. The young specimen measured 20^{mm} in length.

PLATE IV.

Fig. 34. Young Lepidosteus, twenty days old, slightly larger than the stage of the previous day, seen from above.
„ 35. Tail of same, seen in profile.
„ 36. Profile of young, 21^{mm} in length, twenty-four days old.
„ 37. Head of same, seen from above.
„ 38. Young, seen in profile, twenty-five days old.
„ 38*a*. Profile of tail of same, showing commencement of fin-rays of caudal, anal, and dorsal fins.
„ 39. Natural attitude of young Lepidosteus, thirty days old, seen in profile, $\frac{1}{1}\frac{1}{6}$ of an inch long.
„ 40. Tail of young Lepidosteus, thirty-eight days old, of about the same length as the specimen of fig. 39.
„ 40*a*. Pectoral of same.
„ 41. Profile of jaws of same.
„ 41*a*. Commencement of ventrals of same.
„ 42. Head of same, seen from above.
„ 43. Gills of same, in profile.
„ 44. Gills and gill-arches, seen from below.

PLATE V.

Natural attitude of young Lepidosteus (early part of July) after it has assumed to a great measure the coloring of much older specimens. This specimen measured about an inch in length.

V.

RESEARCHES IN TELEPHONY.

By Professor Dolbear.

Presented Nov. 13, 1878.

I began my experiments in Telephony in August, 1876, my first attempts being with a Helmholtz interruptor, using forks whose vibrations were 64, 128, and 256 per second respectively. For a receiver a coil of wire about a small rod of iron, as in Page's experiment in 1837, in which he used an automatic interruptor. I also used several forms and sizes of electro-magnets as receivers.

With all of these arrangements the reproduction of the sound was well marked. The next step was to cause the vibrations produced by the voice to make and break the circuit in a manner analogous to that of the vibrating forks. To this end a platinum wire was made fast to the end of an opeidoscope tube having a membrane of stretched rubber over the end. The wire was bent at right angles at the middle of the membrane, and projected about half an inch from it. This wire was coupled in circuit with the instruments mentioned above as receivers, and the tube being placed at the mouth while the tip of the wire on the membrane dipped into mercury, also into water acidulated, some of the sounds were very audible; but it was necessary to make the membrane vibrate with amplitude enough to break completely the circuit, or no sound whatever could be heard. From this I concluded that the difference of resistance interposed by the vibrations was not great enough. I therefore sought for some means to increase the difference, and made for that purpose a small cone of iron, which was soldered to the wire upon the opeidoscope tube, for the reason that, when the cone was plunged into the mercury, a slight motion of the membrane would materially vary the cross-section immersed and consequently the interposed resistance. With this arrangement no better results were obtained, as it was found that the mercury bounded away from the cone when the latter was vibrating. I therefore sought for other means for varying the current strength.

One is necessarily shut up to the two only possible ways of varying the current; namely, varying the resistance, or varying the electromotive force. I had tried the first with no satisfactory results, and then attempted the second.

In the spring of 1864, while a student in the Ohio Wesleyan University at Delaware, Ohio, I was employed to make a large electromagnet and a large permanent magnet for illustrative purposes at the University. While engaged in making these, I devised a magneto-electric telegraph, in which the currents were to be generated by a permanent magnet thrust into a coil or hollow helix; and these currents were to reproduce like motions upon a permanent magnet at the other end of the line. The device was not dissimilar to the one made by Gauss and Weber of Göttingen, in 1833; but I knew nothing of their work at that time.

In 1873 I observed a deflection of a galvanometer needle, when the stem of a vibrating tuning-fork was held upon the face of a thermopile. The tuning-fork used was a rather large one, giving E^1 of about 78 vibrations per second; the prongs had been made magnetic for other experiments, and the inductive effects of the movements of these poles upon the face of the pile was also noted. The following is the record from my note-book, and dated Aug. 15, 1873: —

"Noticed the effect of the vibrating fork, which was also a permanent magnet, upon the current, when one face of the pile was heated. If the fork was moved no faster than the galvanometer needle would vibrate, once in about 4 seconds, the needle would be set swinging. If the fork vibrates its natural rate, 78 per second, the needle couldn't move, as the current was changed faster than the needle could move."

This was a *vibratory current in a closed circuit* originated by sound vibrations.

I understood this to be simply a particular case of magnetic induction that was familiar enough to every one who was acquainted with Faraday's work; the former experiment I described at the Portland meeting of the A. A. A. S., in 1873, as I thought it to be new. With this experiment, and my invention of 1864, I was prepared with all that was necessary for the plan for a speaking telephone, which was matured and bears the date of Sept. 20, 1876.

"Let a coil of wire be about the pole of a permanent magnet, and the terminals be attached to a galvanometer; then, when a piece of iron approaches the magnet, a current is induced. Suppose that the wires connect with another coil about a permanent magnet; then the

current will affect a piece of iron in front of the poles in the same way as the first is affected. In this way a telephone may be constructed. By making a sound to vibrate a piece of sheet iron in front of one magnet, the ear applied to the other magnet should hear the kind of sound made at the first."

Within a few days of that time, I began the construction of a pair of such instruments, entrusting them to Mr. A. Stetson, a teacher at Rockland, who came to Tufts College on Saturdays to work in the Physical Laboratory. The first ones attempted were begun with a pair of straight-bar permanent magnets belonging to the College; they were 8 or 9 inches long and about half an inch in diameter. The helix was wound directly upon the magnets, while the vibrating armature was glued to an opeidoscope membrane. The first one made I have now, just as it was used at that time; the membrane was made of sheet rubber, and was two and three-eighth inches in diameter. The iron armature glued to it was an inch and a half long by three quarters of an inch broad, rectangular in outline.

Mr. Stetson was employed to make a pair of instruments, in which no battery was to be used, and both instruments were to be alike. Before they were completed, he stopped coming to the College for several weeks, and they were consequently delayed in a manner that they would not have been if I had thought of the very great value of the invention.

I was extremely busy with my college work and also in getting a book through the press, and couldn't attend to it very well myself. About the first of October, the plan of using an armature of iron glued to a membrane was changed to one where the armature was to cover the entire end of the tube and be screwed to it. This was done for two reasons; one being that the armature could not be brought close to the magnet without its adhering to it, and, second, that the vibrations of the voice-sounds could be easily felt when talking against a large piece of rigid paper or piece of board, from which it was inferred that the vibrations of an iron armature would be sufficient to induce the requisite currents. Mr. Stetson started a pair upon this plan at once, but, as I said before, he failed to complete them, as he did not come to College Hill from about the fourteenth of October till some time in December. Early in December, one evening, I took one of the incomplete telephones and endeavored to measure the resistance through which such an induced current would be manifest by means of a Thomson galvanometer and a set of Resistance Coils, and found I could readily get a deflection with an inserted resistance of fifteen thousand ohms, —

the linear limit of my Rheostat, which I reckoned equal to nine hundred miles of ordinary telegraph wire. Up to this time I had thought of the invention solely in its scientific relations, and was not pursuing that as I ought to, as I knew that Prof. Bell had pre-empted the ground. Indeed, I was waiting for an opportunity to see him to tell him to use the permanent magnet, as every account of his work said he was using a battery; but when the great value of the invention was shown to me, and I learned that Prof. Bell patented his work as soon as possible, I concluded to try to profit by it myself. I therefore began at once upon a pair of instruments to that especial end, but before I had time to complete them I heard that the device had already been patented; so I ceased my hurry upon them. Indeed, I didn't finish them for some weeks. In these instruments the magnets were of half-inch round steel, and the bobbins were taken from some old telegraph instruments that I found at Hall's on Bromfield St., as they just suited my purpose. I have these instruments now, and they are very fair telephones, and will do good work.

I next had a pair made in much better shape, and used them in several public exhibitions during the spring and summer of 1877. Upon these instruments I had a flaring horn mouth-piece. At one time I took them to the railroad between Elm St. station and North Avenue station, attached the terminals to the two lines of rails at either end, and was able to converse over the rails in that way. This was on the seventeenth of July, 1877. In the attempts to improve the telephone a great many hundred experiments have been tried, and among them not a few devices that have since been patented by other parties. Among the first of these was the using of a magnet upon each side of the plate; this was done as early as March, 1877, and that device was exhibited at a public exhibition that I gave of the invention early in April of that year, at Tufts College.

In April, I fixed several sets of magnets and bobbins to act upon one plate. The results were no better than when only a single pair was used. In my instruments made in February the magnets were compound horse-shoe magnets, such as could be bought in the stores; and such an arrangement I have uniformly found to be the best for loudness of sounds.

My next improvement consisted of placing a cushion of felt under the vibrating plate; this has been adopted in the making of telephones, as it prevents the too rapid diffusion of the vibrations from contact, and also acts as a damper to absorb the sympathetic vibrations of the plate.

Next it occurred to me that, if the armature of an ordinary sounder,

or relay, could be made to vibrate by sound-vibrations, the corresponding armature of another like instrument in the circuit should respond to the induced current. The armature of an ordinary sounder was first screwed down pretty near to the poles of the magnet, and then the thread from a common string telephone was tied to it, so that the sounds produced in the string telephone should be conveyed by the string to the armature, and thus make it to vibrate. This arrangement was coupled up in electric circuit with a telephone of ordinary pattern, and tried between two distant rooms in a building, with success. Afterwards two like sounders were thus coupled up, and talking was carried on over a circuit nearly half a mile long, using only the sounders with the thread telephone tied to each. The sounders had a resistance of only two or three ohms apiece. Then two relays were tried in like manner, each relay having nearly a hundred ohms resistance, with better results than before. At one time the thread telephone attachment was dispensed with, and the vocal sounds were produced in a small tube held immediately in front of the relay armatures both at sending and receiving instruments. In this way it was easy to hear musical sounds, such as a tune sung; and sentences, if at all familiar, were recognized without much difficulty. But this was of course working under a great disadvantage. I therefore devised a mouth-piece for the armature, and afterwards changed the form of the armature itself, so that it would be adapted to both functions,— that of an ordinary sounder and of a speaking telephone. With such an instrument as I exhibit here, I have worked successfully over the line between Milford, N. H., and Boston, — a distance of fifty miles.

From the first I had interpreted the action of the telephone to be due solely to the ordinary vibrations of the plate being performed in a magnetic field, and varying that field of magnetism. When an ordinary tuning-fork is struck, its vibrations may not only be heard but felt, and also seen; but directly the amplitude decreases, so that it cannot be seen to vibrate, but it can be both felt and heard: but long after it cannot be felt it may still be heard. But no one is at liberty to say that, because the sound only can be heard, the vibrations of the fork differ in any thing than amplitude from those at first seen; and it is admitted generally that such vibrations would be competent to produce such sonorous results as are observed. Nevertheless, there have been several investigators who have stated it as their opinion that the sounds of the telephone were due to some new kind of molecular motion, which was different from an ordinary sound-vibration. To test this view, I constructed a telephone having a mem-

brane of paper carrying a small electro-magnet, with its poles facing the poles of the large inducing magnet. As this has its polarity determined by induction, and the strength of it varying with the distance apart of these facing poles, it is evident that any articulate results obtained under these conditions must be due to the ordinary vibrations to and fro of the disk and magnet upon it. The results with this arrangement were excellent; the articulation was not only good, but it was as loud as in any telephone now in the market. Especially good was it when the electro-magnet was separated from the large magnet by a rather thin piece of rubber, allowing of motion in a longitudinal direction, but not in any other. This I take to be demonstrative evidence that the explanation given above of the telephonic action is true. Diaphragms of other materials were tried, such as wood, zinc, brass, mica, and so on, — a great number. All will work; and paper was found to give the best results, probably because it has rigidity and elasticity enough, while the mass is small, and hence more easily moved by aerial vibrations.

At one time, early in October, it occurred to me to try for a receiver the iron pole of one of the permanent magnets, with its bobbin on of course. That is to say, the permanent magnet was removed, the other conditions remaining as before. With this I was able both to send and receive. Then the iron core was removed, and in its place an ordinary wood-screw an inch and a quarter long was put through the bobbin and screwed into a piece of board three or four inches square, the head of the screw towards the plate. With this arrangement I was still able to receive or send, using the circuit between the College and my house, nearly half a mile long. Now every wood-screw is made slightly magnetic by the process of making the screw, but most wood-screws have but a slight polarity; that used in this experiment was only sufficient to move slightly three or four iron filing bits. Again, experiments were tried with magnets of various forms, — magnets with chambered poles, with poles cut radially, with poles bent at right angles, with wire of various sizes, from No. 22 to No. 37, with the result that No. 28 or 30 seemed preferable for nearly every purpose. The finer wire not only offers so much greater resistance, but in the summer-time it is liable to be injured by lightning. I have had several fine-wire telephones that were injured by the induced current from a flash of lightning a considerable distance away. My line runs for thirty or forty rods under the Somerville fire-alarm wires, and hence would be affected by the inductive action upon them; but between the college building and my house, there is

constantly a current in one way down the hill, and the sputtering of the telephone is sometimes so great, when every thing is quiet out of doors, as to attract attention anywhere in the room. I have several times observed the effect of a thunder-storm upon the line. Generally it happens that before the shower there is nothing to be heard, even though the lightning is only three or four miles away; but while the shower is overhead, the discharges are sometimes so loud from the telephone as to be heard upstairs in my house. And after the shower has passed a long way off, so far that the thunder cannot be heard at all, every flash has a response in my telephone.

A close wound spiral of steel wire was made fast by one end to the middle of the vibrating plate, and the other end to a post seven or eight inches back of it. Within this helix a permanent magnet was so placed as not to touch the coil in any place. It was reasoned that this arrangement should also give sonorous results, as the vibrations of the plate would move the spirals of the coil to and fro across the magnetic field, and thus give rise to corresponding currents in the circuit. This was found to be true; but the results were unsatisfactory, and nothing articulate was heard from it, though some other sounds were. This was also tried by incorporating a battery in the circuit, but with no different results.

A great many experiments were also tried with the view of finding whether the passage of a sound-vibration through an electric conductor would in any way affect the current, to break it up into corresponding pulsations. To this end, batteries of varying elements and strength were coupled to my line, and vibrations set up in the line-wire in various ways, such as by striking, by drawing a resined bow across it, by tying the string telephone to it and making sounds of varying pitch: in none of these was there any observed effects.

Another variation in this experiment was to let a person take the two terminals in a circuit including a battery and a receiving telephone, and, while thus being a part of the circuit, singing and talking in the endeavor to discover if such agitation from sounds as can plainly be felt by one would produce any undulations in the circuit. No such effects were noted.

Three telephones were included in one circuit; two of them close together, the third at a distance. Sounds were produced in the two adjacent ones. It was thought to be possible that the electric waves might neutralize each other if they were sent in opposite directions, if the two had the same intensity, thus furnishing a means of measuring the intensity of sounds; but no such interfering results were noticed.

Nevertheless, it would appear to be theoretically true that such interference should take place under appropriate conditions.

Very many other changes were rung upon the conditions for getting articulate sounds, such as enlarging the bobbins, placing them on both sides of the plate: in one case one was made for a core three inches in diameter, and was used as a tube through which to speak. In another case the bobbin was wound about a pint cup, and a large compound magnet weighing about twenty pounds was placed with one pole close to the bottom of the cup. This made a fair speaking telephone, both as sender and receiver.

Telephones with oval diaphragms, square diaphragms very small and very large, a foot or more in diameter, were made; diaphragm fastened to large resonant surfaces, fastened to the edge, to the middle, to both edge and middle, with magnet fastened to one edge of diaphragm, and the free end of the magnet opposite the middle of it, and so on, — all of these except the largest making good speaking telephones; and these largest when mounted concentrically, leaving a free edge five or six inches all round, make excellent *calls*, as they may be struck with a billet of wood, which starts a current that can be felt in an ordinary receiving telephone, and heard plainly thirty or forty feet away from one. A good many forms of calls were invented, one of them being the so-called "Devil's Fiddle:" a catgut string fastened to the middle of the disk is pulled through a bit of leather with resin on it. The sound of such a device is familiar to every one. I have heard it from a receiving telephone in another room, with the door closed between. Also a tuning-fork call, in which a rather large tuning-fork is made to vibrate and then held so that the vibrations of one leg strike against the telephone plate. This was used as early as January, 1877. Another call consists of a hammer resting lightly upon the plate of the telephone, which will be thrown over by a strong call, and thus ring a bell, or set off an alarm. This can be done with the voice. To measure the amplitude of vibration of such a telephone plate, I had one mounted with a system of levers, one of them carrying a small mirror that reflected a beam of light across the room, when I got a displacement of as much as two feet for some sounds.

So far the experiments have been with the magneto-telephone, where the principle depends upon the varying electro-motive force originating in a magnetic field. But I turned my attention to the other method of varying the current, — namely, by varying the resistance, — and accomplished it in several ways.

First, by making a single battery-cell a sender. If a cell be coupled

up with an ordinary receiver, and one strike with a pencil or snap with thumb and finger one of the elements, the snap will be heard at the telephone. Also if a tuning-fork be held while vibrating upon one of the elements, the sound will be plainly heard. I constructed a single cell of copper-zinc with soldered terminals, the metals being separated by a small piece of rubber tube bent so as to make a cell to hold a dilute solution of sulphuric acid: the metals were about six inches square. With this alone as a sender, when coupled with an ordinary receiver, all sorts of sounds were transmitted, tuning-forks, singing and talking. This was then reduced in size to about that of a watch; the articulation was good, but it has never been very loud. It is better when the tank is filled with water, and a battery current of five or six elements inserted in the circuit.

Second, the Reiss transmitter was modified into the form exhibited, making the plate one terminal and the other a needle-point which could be nicely adjusted by a screw. With this device in a circuit with a battery of any sort, very strong sounds would make and break the circuit, and reproduce the pitch of the sound with great loudness. When the talking was gentle the articulation was very good: one was able to make out every word spoken. When a drop of water was placed between the plate and point, and a weak battery was used, the articulation was excellent; but when a great resistance would permit the use of a strong battery, so as to get a spark of considerable electro-motive force, it became possible to speak and be heard at some distance from the receiving telephone. During a trial of this instrument between Boston and New York last winter, ordinary talking in Boston was heard distinctly in New York, by one who was ten feet distant from the receiving instrument there.

At this time a battery of 100, 125, and 150 gravity cells were used, the best results being obtained with the largest battery. The explanation doubtless is that the air acts as the variable resistant, the vibrations of the plate interposing a greater and less distance between it and the point, the electro-motive force being sufficient at all times to bridge the space. This is the more probable as I have found with the same instrument, and with a greater separation of the plate from the point. If a source of so-called static electricity, as with a Holtz machine, be employed in place of a battery, talking is plainly heard, as I have repeatedly verified over my line.

In place of the point, surfaces of variable dimensions, of various materials, and under many conditions, were tried; surfaces of iron, lead, copper, silver, carbon, in sizes varying from a point up to more than

an inch square, and being in direct contact, or separated by water acidulated; solutions of various sorts, such as nitrate of silver, sulphate of copper, and so on, — all of them being available for the purpose, all of them enabling one to talk and be understood, when an ordinary telephone was used as a receiver. Still further modifications were tried, in which a short wire made fast to the middle of the vibrating plate was covered with a thin coat of wax, except the square end; this placed opposite to another end of wire, and both incased in a small rubber tube filled with mercury. Thus the approach and recession of the points caused by the vibrations of the plate would increase and decrease the resistance in the mercury, while the latter was prevented from bounding away by the pressure of the tube.

In another, a strip of tin was soldered to the plate and bent at right angles so as to project outwards, and the end cut to a point with about ninety degrees included angle; this point rested upon another similar one by light contact, and the current was varied by the amount of surface in contact. The surfaces were also amalgamated and then tried.

Pieces of wood were also screwed to the plate, and then it was saturated with water, with acids, with metallic salts, and with precipitated silver; and in all these ways it was found possible to vary the current sufficient to reproduce sounds, and with almost all of them words were reproduced; that is to say, they were speaking telephones.

All of the above work was done previous to January 1, 1878.

Since then, the chief work has been done with the modification of the transmitter, in which the plate vibrated directly against a point; and the results have been of such a character that I have given a name to the special form, calling it an Electrophone, — a name which I think to be more appropriate even for the common telephone than the name it bears, inasmuch as it is a real conversion of electric energy into sound-vibrations that is effected.

A series of experiments was undertaken to determine if possible the best size for such an instrument, the thickness of the plate, battery power needed, and so on; and to this end I had made an instrument which would admit of the use of a plate varying in size from an inch or less, up to one three inches and a quarter in diameter. I also had a micrometer screw attachment, by which the advancement or recession to the ten thousandth of an inch could be made. Then plates of iron, steel, copper, brass, zinc, lead, tin, plumbago, and graphite were tried, each of a differing size and thickness. With several of these some most excellent results were obtained; for instance, with a plate about

two inches in diameter and one fiftieth of an inch thick, one was able to make himself plainly heard, the articulation being unmistakable anywhere in a room sixteen feet square, while persons thirty or forty feet away would know that one was talking: this over a line about half a mile long and ten gravity cells in circuit. With a stick of graphite the results were about the same. In this case the plate touched upon the slightly rounded surface of a stick half an inch square. Of course singing and strong vocal sounds could be heard very much further: they have been heard fifty feet away from the house by persons in passing carriages. The difficulty has been, and yet remains, to maintain the right pressure of contact. If it be a little too great, the talking sinks to the delicacy of the ordinary telephone; if it be too little, it breaks up so as to give but little except the pitch of the voice; and with the micrometer screw it was not possible to do any better than with an ordinary one. If some device can be invented to keep that uniform, the whole problem of the loud-sounding telephone is solved. A mechanical fixture is all that is needed.

Of all the contrivances tried, the simplest in every way is the following sender: An ordinary tin fruit-can, with one end removed, had one terminal from a battery soldered to it; the other terminal held in the hand so that the circuit was complete when the end of a finger was pressed against the bottom of the can. If, now, one shall talk into the open end of the can, the vibrations of the bottom are sufficient to vary the resistance there enough to render it audible in any ordinary telephone. The resistance of the hand is very great, — 2000 or 3000 ohms; this may be lessened somewhat by wetting the hand, and this improves the effect. In like manner, one may fasten the second terminal of a battery to a stick of gas-carbon, two or three inches long, and, holding the tip of it at an acute angle with the bottom of the can, make himself understood by talking into it.

Most of these investigations have been mechanically carried out by Mr. H. C. Buck, to whose skill and ingenuity I am under many obligations; I have also received considerable assistance of like sort from Mr. W. L. Hooper. To both of them I would express my gratitude for their interest and fidelity.

It was remarked upon a previous page, that one is limited to but two methods in the making of a speaking telephone. This will become evident at once upon the consideration of Ohms's law. All forms of electric telephones depend for their action upon variable electric currents, and hence must conform to the general law of currents. This law is, that the current varies as the electro-motive force

divided by the resistance, and, where proper units are taken, it may be represented thus: —

$C = \frac{E}{R}$, where C is the current, E the electro-motive force, and R the resistance in the circuit. Now electro-motive force depends upon the origin of the electricity. When batteries are used as the source of electricity, the electro-motive force may be modified by coupling cells in series or sets; but if a single cell be used, its electromotive force is a constant quantity which depends upon the chemical relations of the substances employed. To modify electro-motive force from batteries is entirely impracticable. Not so, however, the electricity derived from magneto-electric machines. Here the velocity of the armature modifies the electro-motive force. The mechanical motion of an armature in a magnetic field re-acts upon the magnet in such a way as to develop a current with electro-motive force proportional to its velocity; the essential thing being the motion of an inductive substance like iron or steel. Seeing that a piece of iron may be made to move rapidly by sound-vibrations, it is plain that such vibrations in a magnetic field will originate currents of electricity with a great electro-motive force; for the rapidity of the vibration of the plate for ordinary speech will be for a man's voice in the neighborhood of 125 per second for the fundamental sound, to say nothing of the overtones. Professor Bell started with the right principle, and, however faulty his first instrument was, it involved the generic idea, as the subsequent development so fully corroborates. Now there are two distinct methods by which the vibratory currents may be set up; namely, by electro-magnets and by permanent magnets. With the first, the action of the armature in the origination of the currents is part of the time to send a wave in the same direction as the current already in the line, and a part of the time to send one in the opposite direction; in other words, it will alternately increase and decrease the current on the line, and this not only by its inductive action upon the magnet, but by its inductive action upon the current circulating in the bobbin, whereas with the permanent magnet there is the inductive action of the armature upon the magnet and coils, while the only electricity in the circuit originates in the coils. The former method originated with Professor Bell, the latter with myself. Some there are who think the two to be identical. I think they hardly can be identical; for in the case of an electro-magnet, when induction is thus utilized, there is not only magnetic induction upon the magnetic core, but there is also electric induction, — that is, induc-

tion upon the current within the coils, — whereas with permanent magnets there is only the first magnetic induction.

Improvements in this direction can hardly be expected, further than to utilize fully the currents which we already get; and these, I am sure, are not fully utilized. For it is not an uncommon experience with my instruments, that the vibrations are strong enough to be very perceptible by the hand upon the instrument; and thus it appears to be like a tuning-fork held in the hand: when struck, the sound is not given out to the air, but is smothered as it were in the hand; but, unlike the fork, it will not be perceptibly louder when placed upon a large resonant surface. It is not improbable that much of this spent energy manifests itself as heat in the plate; but I have not yet investigated this.

There is no third method of varying these primal conditions. These two methods cover the ground of varying the current by means of a change in the electro-motive force.

With the other term, resistance, the case is very different. A change in resistance may be effected by lengthening the conductor, by changing its cross section, by interposing various substances having different conductivities, by varying the density of a loose-grained conductor, and in other ways, each one of the methods mentioned being capable of application in very many different ways. Hence, telephones constructed upon the plan of varying the resistance have been invented in great variety, and by many different persons. Historically, Page, of Salem, stands first; his automatic interruptor being still employed for many purposes, and, when used as he used it in connection with an electro-magnet as a receiver, it was a genuine telephone. This was in 1837. Next, Reiss, of Germany, varied the resistance by platinum terminals when contact pressure was variable; this was in 1861. It would seem that if Reiss had tried an ordinary relay, or some such instrument for a receiver, in place of the one which he did use, he would have had then a good speaking telephone. What was lacking then, was an armature to his receiving magnet. Gray, of Chicago, in February, 1876, used water for the same purpose. In August, same year, I varied the cross section in mercury with the iron cone. In January, 1877, Edison adopted carbon in the form of lamp-black between a vibrating plate and a stiff backing. In December, 1877, I varied the contact pressure between the battery elements, and still later Hughes used free carbon saturated with mercury, and called his instrument a Microphone. The so-called microphone does not differ in any essential thing from the other telephones which have been in use for a good while. The name microphone

is a misnomer, for it does not magnify weak sounds; it simply reproduces them close to the ear. When it is said that a fly can be heard to walk, the function of distance is left out of the account. One cannot hear a fly walk at the distance of three or four feet; but if one can get a fly to walk upon his ear, or upon a plate, like a telephone plate held at his ear, he will find that he can hear the fly walk; and the only reason he doesn't hear it walk under ordinary circumstances is because the fly is too distant. One cannot hear a man walk a mile away, but a telephone will enable him to hear him walk; but one ought not to say that the sound is magnified. The function of a telescope is to make distant objects appear to be nearer; the function of a microscope to make minute objects appear larger. Under no circumstances can a microphone make a walking fly to be heard by one holding a telephone at arm's length from his ear; its function is, therefore, to reproduce distant sounds close to the ear, and it is therefore simply a telephone. Neither does its action require us to modify in the least the general statements concerning sound-vibrations in a body. Whenever there are two surfaces in contact, and one of them is subject to sound-vibrations, the pressure at the two surfaces must vary with the phase of the vibration, and a current of electricity must vary with such pressure. This is strictly in accordance with Ohms's law, and with experience.

If one may borrow from Natural History a terminology applicable to these cases, it may be said that there are two genera of telephones, — the electro-motive and the variable-resistant. These two differ from each other in every essential particular. Of the first there are two species; the electro-magnetic, and the magneto-electric. Of the second there are very many species already, and it is evident that there may be many more.

The synoptical table appended shows at a glance the relations specified above: —

	Genera.	Species.			
Sound-vibrations acting under such mechanical conditions as to modify an electric current by varying the	Electro-Motive Force.	*Permanent Magnets,*	varying a current already on the line	DOLBEAR, Aug.,	1873
		Electro Magnets,	varying a current already on the line	BELL, Spring,	1876
		Permanent Magnets,	originating the only current on the line. . . .	DOLBEAR, Sept.,	1876
	Resistance.	*Automatically*		PAGE,	1837
		Platinum Contact,	varying pressure . . .	REISS,	1861
		Water,	„ space	GRAY, Feb.,	1876
		Iron Cone in Mercury,	„ cross-section .	DOLBEAR, Aug.,	1876
		Carbon,	„ pressure . . .	EDISON, Jan.,	1877
		Battery Elements,	„ „	DOLBEAR, Dec.,	1877
		Carbon-Microphone,	„ „ . . .	HUGHES, Spring,	1878

Thus it is seen that the two different methods of producing speaking telephones are as unlike each other as a battery is unlike a magneto-electric machine, which, though they have the same function,— namely, to produce electricity,— there is nothing else that is common They may be compared for efficiency, not for involved principles.

Suggested Uses.

I see no reason why the variability of conductivity due to pressure, as in the case of carbon is so marked, might not be used in many places where now are such instruments as thermometers and barometers. Thus the expansion and contraction of an ordinary copper rod, or, better still perhaps, a thin copper tube, might be made to act upon a piece of carbon in circuit with a constant battery, and the galvanometer needle would constantly indicate the temperature if properly callibrated.

In like manner, the varying pressure of the atmosphere could be made to be much more apparent than now. Perhaps a wind-gauge would also be possible. Especially would it be possible to measure the depth of water by its pressure upon a carbon disk when sunk into the water. Here it would be necessary to have a double-line wire through which the circuit could be maintained during the whole time of the descent; that is to say, the length of wire in the circuit would need to be constant. If the temperature of the water be known, as it generally is, the depth would be easily read off from the galvanometer.

INVESTIGATIONS ON LIGHT AND HEAT, made and published wholly or in part with appropriation from the RUMFORD FUND.

VI.

ON CERTAIN REMARKABLE GROUPS IN THE LOWER SPECTRUM.

BY PROFESSOR S. P. LANGLEY.

Presented Oct. 7, 1878.

IN first studying the diffraction spectrum for the purpose of learning more of the laws governing the selective absorption of the sun's radiant energy, both near its surface and in our own atmosphere, I was much struck, as others have doubtless been, with the remarkable band of lines on the less refrangible side of B. Seen under great dispersion, they were quite unlike any thing I had before observed in the spectrum, while the best maps, I found, gave no adequate idea of their curious structure which possessed to me an unexampled formal regularity. After more study of this portion, I commenced critically to examine the A group, which is nearly the last extremity of the visual spectrum toward the red, and which is so overwhelmed in the diffuse light from brighter portions, that few have, I believe, ever seen it in any detail. I now found another subject of surprise, in the extraordinary resemblance which this group bore to the B group; a resemblance which could not be the result of accident, but which has never been, so far as I can learn, publicly noticed, and of which no published map, I have seen, gives any idea.

It is, of course, known to professional students that in this region such a structure and general resemblance exist; but as I believe that, without special precautions, its extraordinary completeness cannot be made out, it is possible that a very careful drawing, founded wholly on micrometric measurement, of what has never been fully delineated will present some novelty even to the spectroscopist who may not have made this region a special study. To others I may recall —

what any one who has only the slightest acquaintance with the appearance of the whole visible spectrum must have noticed — the entirely casual way in which the lines, all along from red to violet, are juxtaposed. There is no more apparent order in their arrangement than in that of undergrowth in a primitive forest, or of any other disposition of natural objects which we assign to chance. But, if in walking through such a forest, we came to an open space in which the trees were planted two and two, with the most formal regularity, we should hardly doubt that something else than chance had been at work. If we measured the distances and found that these pairs had been set out with such precision that our best instruments could detect no difference between them; if we further found that the spaces between the pairs were themselves not casual, but arranged with exactness in a certain progression, — if we found all this, we should certainly, in the use of ordinary language, say that here Nature had given place to art. If, further on, we saw a second arrangement like the first, which resembled it closer the more we examined, we should find our conclusion for design, if possible, strengthened. It will be seen, I think, that precisely this abrupt transition from confusion to order and symmetry exists in the spectrum, as well as in the singular duplication of the design. What might be called the result of intelligence, if observed in another field of Nature, we must here call conclusive evidence of the existence of law. No accident, but some still hidden law, has regulated, I do not doubt, the curious relations now exhibited. Perhaps, with regard to them, we may be standing ourselves in the same position as those few did who were enabled to contemplate the Fraunhofer lines in the first years of their discovery, and recognize that, though we cannot find their meaning, it promises to be worth knowing.

I had at first meant to present to you some attempts of my own toward a solution. Afterward, considering how little I knew, it seemed to me better to offer nothing in the way of hypothesis now, but for the present to limit myself to furnishing facts, necessary in the creation of any future theory, in the shape of the results of exact measurement. These are given in the accompanying pages, and give sufficiently exact data, I hope, for determining the laws of the numerical harmonies here so plainly latent.

The best drawings of the A lines I have seen are those recently given by Professor C. Piazzi Smythe, Astronomer Royal for Scotland. They were obtained in June, 1877, at Lisbon, whither Professor Smythe made a special voyage to obtain a high sun and clear sky. I

reproduce an exact copy of these with those of Kirchoff. It must, however, be remembered that Kirchoff's and Smythe's drawings, made with prisms, will present a slightly different collocation from those made with a grating. I give also both Kirchoff's and Angstrom's drawings of B, that it may be seen how far justice has been done heretofore to this interesting region in the best maps. In my own, every line is given from repeated micrometric measurement. I have only given part of the A group, therefore, which extends much further, but in so faint a light that I have not felt sure of my measures beyond A_{12}. The relative intensities only are the result of estimate. The scale is double Angstrom's. I have made as yet no studies below the A group, but have discovered an unnoticed analogous group more refrangible than B, which appears in the air-spectrum, and which I do not give, as all these studies belong exclusively to the high sun. From the successive appearances of these three groups, however, I have drawn the inference that the spectrum below A, if ever rendered visible, will probably present a strikingly different type from that above B.

As Captain Abney has lately succeeded in photographing as low as A or lower, it may be proper for me to observe that the general character of the observations here given in detail was, with drawings of A and B, briefly presented by me to the notice of the National Academy, in Washington, in 1877. I have executed this work with apparatus partly due to the Rumford fund, and therefore have delayed a full presentation till I could ask to be allowed the honor of submitting it to the American Academy.

I have been assisted in these measurements by Mr. R. F. Hall and Mr. F. W. Very.

The spectroscope with which these observations have been made is provided with two telescopes of 1.66 inch aperture and of 20.01 inches focal length, which are fixed in the walls of the cylindrical chamber containing the diffraction grating. The angle between the optical axes of the telescopes is fixed here, and it amounts to about 61° 16′. The grating is fastened to a revolving plate. A filar micrometer is attached to the observing telescope. The diffraction grating used is of speculum metal, and is one of the largest made by Mr. Rutherfurd, the actual size of the ruled portion being 1.75 inch square, containing 17,296 lines to the linear inch.

The object of these measurements was to obtain the relative distances between the lines, rather than their absolute wave-length. The distances of the several components from the first line of each group

have been measured with the micrometer. Then, the first line of the group being assigned the value of zero, and the distance from this line to the one numbered 12 being called unity, the relative distances of the intermediate lines are expressed in decimal fractions, which are multiplied by the difference in wave-length of the limiting lines, and the products added to the wave-length of the more refrangible one, which is distinguished in each case by a subscript zero attached to its cognominal letter. It is evident that for these small angles, the largest of which does not exceed 30′, the sine differs so inappreciably from the arc, that the readings of the micrometer may be converted directly into angular measure. The difference between the wave-lengths of the limiting lines of the group has been taken from Angstrom's measurements in the case of the large B group. The line called A_{12} in this paper was not measured by Angstrom. Its wave-length has been approximately determined by the following method: —

The centre of the comb being midway between two known lines of the spectrum, the difference of micrometer readings for these lines was observed. Let the angular distance between them be $2x$. Then from the general formula $nS\lambda = \sin i + \sin r$, where $S = 681$ lines to the millimeter, and n is 1, we have —

$$\left.\begin{array}{l} 1 \times 681 \times \lambda_1 = -\sin i + \sin (r - x) \\ 1 \times 681 \times \lambda_2 = -\sin i + \sin (r + x) \end{array}\right\} \text{ also } r + i = 61^\circ\ 16'$$

Measures taken without disturbance of the micrometer focus gave —

Angstrom	(6561.8) C	to	Angstrom	(6716.4)	$= \overset{\text{rev.}}{14.942}$
"	(6716.4)	"	"	(6866.8) B_0	$= 14.490$
"	(6866.8) B_0	"	"	(6927.8) B_{12}	$= 6.087$
	A_0	"	"	A_{12}	$= 7.727$

Substituting these numbers in the appropriate equations, and solving, we have —

$$C \quad 681 \times \overset{\text{m.m.}}{0.000}\ 6561.8 = .44686 = -\sin i_1 + \sin (r_1 - x_1).$$
$$(6716.4)\ 681 \times 0.000\ 6716.4 = .45739 = -\sin i_1 + \sin (r_1 + x_1).$$
$$i_1 = 15^\circ\ 24'\ 02'' \qquad r_1 = 46^\circ\ 51'\ 58''$$

whence $2x_1 = 51'\ 57'' = \overset{\text{rev.}}{14.942} \therefore \overset{\text{rev.}}{1.} = 3'\ 28''.6.$

We have again —

$$(6716.4)\quad 681 \times \overset{\text{m.m.}}{0.000}\ 6716.4 = .45739 = -\sin i_2 + \sin (r_2 - x_2).$$
$$B_0 \quad 681 \times 0.000\ 6866.8 = .46763 = -\sin i_2 + \sin (r_2 + x_2).$$
$$i_2 = 15^\circ\ 02'\ 30'' \qquad r_2 = 46^\circ\ 13'\ 27''$$

whence $2x_2 = 50'\ 54'' = \overset{\text{rev.}}{14.490} \therefore \overset{\text{rev.}}{1.} = 3'\ 30''.8$.

The mean of these values, $3'\ 29''.7$ is taken as the value of one revolution of the micrometer head in arc, at the time the above measures were made on B_{12} and A_{12}, and B_0 to $B_{12} = \overset{\text{rev.}}{6.087} = 21'\ 16''.4$, A_0 to $A_{12} = \overset{\text{rev.}}{7.727} = 27'\ 00''.4$.

For B_0, (1) $681 \times 6866.8 = .46763 = -\sin i + \sin (r - 10'\ 38''.2)$
" B_{12}, (3) $681 \times \lambda\, B_{12} = \qquad = -\sin i + \sin (r + 10'\ 38''.2)$
(2) $i + r = 61^\circ\ 16' \qquad i = 14^\circ\ 47'\ 38''$

Substituting in (3) the values of i and r found by (2), we have $\lambda\ B_{12} = \overset{\text{m.m.}}{0.000}\ 6928.0$. The value of the corresponding line in Angstrom is $\overset{\text{m.m.}}{0.000}\ 6927.8$.

The result of this example showing a sufficiently near approach to accuracy for our purpose, the same method was used for determining the wave-length of A_{12}, starting with the known value of A_0. Measurements at this part of the spectrum are more difficult than in the more brightly illuminated portion. Three attempts, on as many different days, gave —

$$\lambda\ A_{12} = \overset{\text{m.m.}}{0.000}\ 7678.4$$
$$0.000\ 7677.8$$
$$0.000\ 7679.4$$

The mean of these $= 0.000\ 7678.5$ was taken as the value of $\lambda\ A_{12}$.

The stray light of higher refrangibility and greater illuminating power than the red, and which is reflected from the lens, overpowers the red to such an extent that some means of removing it is necessary. For this purpose, a small direct-vision prism, placed over the slit, allowing only the red to pass, seems best; but red glasses have been found to answer nearly as well.

The following are the unreduced micrometric measurements of the lines in the *A* group.

The numbers in each column are the original micrometric readings, which were taken consecutively without disturbance of the instrument. The different series were taken at various dates.

Beginning of A_0	5.991	6.104	1.808	1.340		1.780
End of A_0	8.295	8.352	2.843	2.880		
A_1	8.750	8.899	3.219	3.214	5.822	4.456
A_2	9.121	9.192	3.337	3.452	5.505	4.759 4.900
A_3	9.459	9.595	3.608	3.700	5.144	5.102 5.254
A_4	9.880	9.981	3.921	4.012	4.739	5.431 5.652
A_5	10.349	10.415	4.219	4.276	4.312	5.887 6.090
A_6	10.776	10.827	4.537	4.538	3.900	6.350 6.523
A_7	11.284	11.323	4.861	4.848	3.425	6.798 6.980
A_8	11.815	11.809	5.197	5.212	2.962	7.307 7.478
A_9	12.327	12.341	5.522	5.569	2.421	7.787 7.964
A_{10}	12.918	12.948	5.901	5.930	1.894	8.327 8.528
A_{11}	13.495	13.490	6.238	6.282	1.393	8.891 9.046
A_{12}	14.071	14.090	6.700	6.650	0.747	9.424 9.587
	14.604	14.682			0.180	

The following are the remainders left after subtracting the micrometer reading of the line called A_0 from the readings of the other lines in the A group.

A_0		A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	A_{11}	A_{12}	
GRATING RIGHT.														
0.000	2.304	2.759	3.130	3.468	3.889	4.358	4.785	5.293	5.824	6.336	6.922	7.504	8.080	8.610
0.000	2.248	2.795	3.088	3.491	3.877	4.311	4.723	5.219	5.705	6.237	6.844	7.386	7.986	8.578
0.000	2.288	2.771			3.795		4.740		5.805		6.761		7.932	8.274
0.000		2.690	3.007	3.368	3.773	4.200	4.612	5.087	5.550	6.091	6.618	7.119	7.765	
0.000		2.676	3.050	3.398	3.761	4.208	4.657	5.109	5.612	6.094	6.647	7.188	7.726	
GRATING LEFT.														
0.000	1.535	1.911	2.029	2.300	2.613	2.911	3.229	3.553	3.889	4.214	4.593	4.930	5.392	
0.000	1.540	1.874	2.112	2.360	2.672	2.936	3.198	3.508	3.872	4.229	4.590	4.942	5.310	

Then follow the quotients obtained by dividing each of the numbers in the preceding table by the difference between the micrometer readings of A_0 and A_{12}.

GRATING RIGHT.

	A_0		A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	A_{11}	A_{12}
	0.0000	0.2851	0.3415	0.3874	0.4202	0.4813	0.5394	0.5922	0.6551	0.7208	0.7842	0.8567	0.9287	1.0000
	0.0000	0.2815	0.3500	0.3867	0.4371	0.4855	0.5398	0.5914	0.6535	0.7144	0.7810	0.8570	0.9249	1.0000
	0.0000	0.2885	0.3493			0.4784		0.5976		0.7318		0.8524		1.0000
	0.0000		0.3464	0.3873	0.4337	0.4859	0.5409	0.5940	0.6551	0.7148	0.7844	0.8523	0.9168	1.0000
	0.0000		0.3464	0.3948	0.4398	0.4868	0.5448	0.6028	0.6613	0.7264	0.7888	0.8604	0.9304	1.0000

GRATING LEFT.

	0.0000	0.2900	0.3529	0.3977	0.4445	0.5032	0.5529	0.6023	0.6607	0.7292	0.7964	0.8644	0.9307	1.0000
	0.0000	0.2847	0.3544	0.3763	0.4266	0.4846	0.5399	0.5989	0.6590	0.7213	0.7815	0.8518	0.9143	1.0000

The mean of the above numbers is given in the next line:—

Mean value A_0 to $A_{12} = 1$	0.0000	0.2860	0.3487	0.3884	0.4351	0.4865	0.5429	0.5970	0.6574	0.7227	0.7860	0.8564	0.9243	1.0000

Multiplying the means by 77.6^{-10}_{m}, and adding the results to 7600.9^{-10}_{m}, we get—

Mean val. $^{-10}_{m}$ $\times$ 77.6	00.00	22.20	27.07	30.14	33.77	37.75	42.13	46.34	51.03	56.08	60.99	66.46	71.73	77.60
Last + λA_0	7600.9	7623.1	7628.0	7631.0	7634.7	7638.6	7643.0	7647.2	7651.9	7657.0	7661.9	7667.4	7672.6	7678.5

The last line gives the values of the members of the A group in wave-length.

The following are micrometric measures of the very close lines (17 in number) composing the B_0 band.

They have been distinguished by small letters of the alphabet (a to q).

B_0 group.				
a	0.897	0.876	0.298	0.296
b	0.923	0.906	0.320	0.319
c	0.990	0.976	0.365	0.382
d	1.042	1.019	0.412	0.400
e	1.082	1.070	0.471	0.465
f	1.171	1.168	0.548	0.560
g	1.263	1.260	0.669	0.648
h	1.309	1.303	0.690	0.700
i	1.399	1.387	0.779	0.780
j	1.444	1.423	0.834	0.825
k	1.540	1.518	0.926	0.920
l	1.628	1.607	1.008	1.000
m	1.709	1.710	1.115	1.103
n	1.825	1.826	1.222	1.217
o	1.923	1.908	1.301	1.306
p	2.043	2.040	1.425	1.438
q	2.156	2.146	1.543	1.536
B_1 . . .	. . . .	. . . .	1.910	1.909
B_{12} . . .	. . . .	. . . .	6.403	6.385

The following are the unreduced measurements of the principal lines in the B group:—

B_0 *a*	16.379	3.949	3.953	6.537	6.529
B_0 *q*	15.131	5.198	5.200		
B_1	14.749	5.575	5.554	8.172	8.168
B_2	14.559 14.468	5.818	5.807	8.367 8.440	8.340 8.436
B_3	14.243 14.139	6.134	6.125	8.662 8.758	8.666 8.764
B_4	13.896 13.818	6.440	6.444	8.997 9.100	8.997 9.117
B_5	13.549 13.454	6.807	6.815	9.369 9.455	9.350 9.450
B_6	13.162 13.067	7.187	7.190	9.746 9.854	9.711 9.820
B_7	12.741 12.652	7.595	7.598	10.164 10.265	10.150 10.228
B_8	12.322 12.216	8.044	8.038	10.584 10.650	10.559 10.664
B_9	11.849 11.760 11.725	8.490	8.478	11.076 11.150	11.065 11.140
B_{10}	11.404 11.315	8.961	8.957	11.522 11.628	11.528 11.596
B_{11}	10.909 10.836	9.439	9.440	12.012 12.100	12.010 12.085
B_{12}	10.292	10.013	10.032	12.624	12.616
Sharp line,	9.890				
Centre faint pair,	9.451				
Delicate pair, (1)	9.307				
Delicate pair, (2)	9.253				
Faint line,	9.049				
Faint line,	8.883				
Very faint line,	8.735				
Strong line,	8.516				
Strong line,	7.600				
End of group,	7.141				

The following are the remainders left after subtracting the micrometer reading of the line called B_0 from the readings of the other lines in the B_0 band:—

a	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*	*j*	*k*	*l*	*m*	*n*	*o*	*p*	*q*
0.000	.026	.093	.145	.185	.274	.366	.412	.502	.547	.643	.731	.812	.928	1.026	1.146	1.259
0.000	.030	.100	.143	.194	.292	.384	.427	.511	.547	.642	.731	.834	.950	1.032	1.164	1.270
0.000	.022	.067	.114	.173	.250	.371	.392	.481	.536	.628	.710	.817	.924	1.003	1.127	1.245
0.000	.023	.086	.104	.169	.264	.352	.404	.484	.529	.624	.704	.807	.921	1.010	1.142	1.240

Then come the quotients obtained by dividing each of the above numbers by the difference between the micrometer readings of B_0 and B_{12}.

a	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*	*j*	*k*	*l*	*m*	*n*	*o*	*p*	*q*
0.0000	0.0042	0.0151	0.0236	0.0301	0.0446	0.0594	0.0670	0.0817	0.0890	0.1051	0.1190	0.1321	0.1510	0.1669	0.1865	0.2048
0.0000	0.0049	0.0163	0.0233	0.0316	0.0474	0.0625	0.0695	0.0830	0.0890	0.1049	0.1190	0.1357	0.1545	0.1679	0.1804	0.2066
0.0000	0.0036	0.0110	0.0187	0.0284	0.0410	0.0609	0.0643	0.0789	0.0879	0.1030	0.1165	0.1340	0.1516	0.1644	0.1848	0.2042
0.0000	0.0038	0.0141	0.0171	0.0277	0.0433	0.0577	0.0663	0.0794	0.0868	0.1023	0.1154	0.1323	0.1511	0.1657	0.1874	0.2033

Below are the numbers obtained by subtracting the reading of B_0 from that of the other lines in the B group: —

B_0 (a)	B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8	B_9	B_{10}	B_{11}	B_{12}	Sharp line.	Strong line.	Strong line.	End of group.
0.000	1.630	1.865	2.188	2.522	2.878	3.265	3.683	4.110	4.583	5.020	5.507	6.087	6.489	7.863	8.779	9.238
0.000	1.626	1.869	2.185	2.491	2.858	3.238	3.646	4.095	4.541	5.012	5.490	6.064				
0.000	1.601	1.854	2.172	2.491	2.862	3.237	3.645	4.085	4.525	5.004	5.487	6.079				
0.000	1.635	1.866	2.193	2.511	2.875	3.263	3.677	4.080	4.576	5.038	5.519	6.087				
0.000	1.639	1.859	2.186	2.528	2.871	3.236	3.660	4.082	4.575	5.033	5.518	6.087				

These numbers, divided by the difference between the readings of B_0 and B_{12}, give the next.

B_0 (a)	B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8	B_9	B_{10}	B_{11}	B_{12}	Sharp line.	Strong line.	Strong line.	End of group.
0.0000	0.2678	0.3064	0.3595	0.4143	0.4729	0.5364	0.6050	0.6751	0.7530	0.8247	0.9046	1.0000	1.066	1.292	1.442	1.518
0.0000	0.2681	0.3082	0.3603	0.4108	0.4712	0.5339	0.6012	0.6751	0.7484	0.8264	0.9053	1.0000				
0.0000	0.2634	0.3050	0.3574	0.4099	0.4709	0.5325	0.5996	0.6705	0.7444	0.8231	0.9028	1.0000				
0.0000	0.2686	0.3066	0.3602	0.4126	0.4724	0.5360	0.6040	0.6704	0.7518	0.8277	0.9067	1.0000				
0.0000	0.2693	0.3054	0.3591	0.4154	0.4718	0.5316	0.6013	0.6707	0.7516	0.8269	0.9065	1.0000				

The measured intervals between the components of pairs, treated in the same way, become —

B_2	B_3	B_4	B_5	B_6	B_7	B_8	B_9 Triples.		B_{10}	B_{11}
0.091	0.104	0.078	0.095	0.095	0.089	0.106	0.089	0.035	0.089	0.073
0.073	0.098	0.103	0.086	0.108	0.101	0.066	0.074		0.106	0.088
0.098	0.098	0.120	0.100	0.109	0.078	0.105	0.075		0.068	0.075
These on the scale of B_0 to $B_{12} = 1$ are next given —										
0.0150	0.0171	0.0128	0.0156	0.0156	0.0146	0.0174	0.0146	0.0058	0.0146	0.0120
0.0120	0.0158	0.0169	0.0141	0.0177	0.0166	0.0108	0.0122		0.0174	0.0145
0.0158	0.0161	0.0197	0.0164	0.0179	0.0128	0.0173	0.0123		0.0112	0.0123
The means of the intervals are —										
.0143	.0163	.0165	.0154	.0171	.0147	.0152	.0130		.0144	.0129

The first line in the following table gives the value of the components of the B group on the scale B_0 to $B_{12} = 1$. The difference of wave-length corresponding to this interval is 61 tenth meters, and the numbers in the second line are obtained by multiplying those in the first by 61.

	B_0 a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q
Mean value, B_0 to $B_{12} = 1$	0.0000	0.0041	0.0141	0.0207	0.0295	0.0441	0.0601	0.0668	0.0808	0.0882	0.1038	0.1175	0 1335	0.1521	0.1665	0.1856	0.2047
Mean val. × 61 $^{-10}$ m	00.00	00.25	00.86	01.26	01 80	02.69	03.67	04.07	04.93	05 38	06.33	07.17	08.14	09.28	10.16	11.32	12.49
Last + λB_0	6866.8	6867.0	6867.7	6868.1	6868.6	6869.5	6870.5	6870.9	6871.7	6872 2	6873.1	6874.0	6874.9	6876.1	6877.0	6878 1	6879.3

After these operations, the products in line two being added to the wave-length of B_0 give the final *wave-lengths* contained in line three.

	B_0	B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8	B_9	B_{10}	B_{11}	B_{12}	Sharp line.	Strong line.	Strong line.	End of group.
Mean value, B_0 to $B_{12} = 1$	0.0000	0.2674	0.3063	0.3593	0.4126	0.4718	0.5341	0.6022	0.6724	0 7498	0.8258	0.9052	1.0000	1.066	1.292	1.442	1.518
Mean val. × 61 $^{-10}$ m	00.00	16.31	18.68	21.92	25.17	28.78	32.58	36.73	41.02	45.74	50 37	55.22	61 00	65.03	78.71	87.96	92.60
Last + λB_0	6866.8	6883.1	6885.5	6888.7	6892.0	6895.6	6899.4	6903.5	6907.8	6912.5	6917.2	6922.0	6927.8				

Mean interval between components of pairs = 0.0150 (B_0 to B_{12} = 1.)

In wave-lengths „ „ „ „ „ = 00.92 $^{-10}$ m

INVESTIGATIONS ON LIGHT AND HEAT, made and published wholly or in part with appropriation from the RUMFORD FUND.

VII.

ON THE TEMPERATURE OF THE SUN.

BY PROFESSOR S. P. LANGLEY.

Presented Oct. 9, 1878.

IT is known to all that there is a problem of the highest interest in solar physics at present waiting solution: I mean that of the temperature of the sun; and, so far as the whole radiant energy is inferable from the rate of emission of heat, the problem is one the theoretical solution of which is evidently dependent on our knowledge of the laws of cooling.

Every operation of Nature, whether in the organic or inorganic kingdom, is accompanied by the emission or absorption of heat; and, considering that, whether the subject of observation be the germination of a seed, the heat of a stove, or the outflow from the sun upon the planetary system, we want to know the rate of the deperdition of energy, one might certainly suppose that no physical law would have been better ascertained; but we are here, however (at least in regard to high temperatures), in a state of nearly complete ignorance, and know almost literally nothing about what so intimately concerns us. This is a reproach to modern physics, which has probably made no real advance here since Newton. To justify this language, I remark that, in the case of the solar temperature, the *amount* of heat the sun sends us is scarcely in question, as we are all substantially agreed on the way to measure this and on the results of measurement. The latest of these give, it is true, larger values than those of Pouillet, which were about 1.75 calories per centimeter per minute instead of 2.50; but these considerable variations are so trifling compared with those in the deductions made from them, that we may still say there is substantial agreement as to data. From like data, then, Sir John Herschel concludes that the temperature of the solar surface is over 5,000,000° centigrade; Mr. Ericsson, whose labors on this point deserve wider recognition, is confident that the temperature is

not materially different from 4,000,000° Fahrenheit; Father Secchi, in his latest research, makes it 133,000° C.; Sir Wm. Thompson and others estimate 30,000 to 60,000° C.

These extremely gross discrepancies having drawn general attention, many distinguished French physicists have lately reinvestigated the subject, and, using Dulong's and Petit's formula, have after most elaborate research arrived at the nearly unanimous conclusion that the temperature of the solar surface is altogether lower than any of these, — is in any case not more than 2000 to 2500° C, but is more probably below than above the temperatures which are reached in our furnaces, and in fact is probably less than that of melting platinum.

It is here to be borne in mind that we really know nothing about the absolute emissive capacity of the solar surface, and that to simplify the problem, when we speak of the sun's being at a lower temperature than that of a certain lamp-black surface or hot platinum or steel, it is assumed for the purpose of comparison, by myself as well as by the above-named investigators, that both the solar and terrestrial sources of heat have the same emissive capacity. The temperature thus defined has been called the "effective" temperature.

M. Violle, one of the most distinguished students of the subject, whose experiments bear evidence of intelligent care, found by observations at Grenoble, in March, 1874, that, with an emissive power thus defined, the temperature of the solar surface was 1230° C.* In a subsequent memoir, he finds for the same the rather higher value of 1354° C.† After allowing for absorption in our atmosphere, it remains true that the temperature is then much below that of melting platinum, and this seems to be confirmed by his later results, which give about 1550° C. as the highest "effective" temperature.

All these and other observations involve the use of the empirical formula, well known as that of Dulong and Petit, which has replaced the earlier and simpler one of Newton.

Now, whatever be the apparent presumption of opposing my opinion to that of so many conscientious and recent investigators, I feel there is something yet to be said; and the present paper is an account of experiments of a special character, undertaken at the expense of the Rumford fund, not with the hope of at once solving so arduous a problem, but with the wish, in this confusion of opinion, to contribute one or two incontrovertible facts as material towards the con-

* Comptes Rendus, vol. lxxviii. p. 1425.

† C. R. vol. lxxviii. p. 1816.

struction of future theory. I hope to show convincingly that the sun's "effective" temperature is at any rate far above that of any ordinarily attained in the arts (very much above that of melting platinum for instance), and incidentally that the law of Dulong and Petit is untrustworthy precisely where we need to apply it.

If we have no formula by which to infer the temperature of the sun, there remains the comparison of its radiation with that of a terrestrial source of high *known* temperature. Thus the late Father Secchi has measured the radiation from the electric arc, and M. Violle that from a Siemens-Martin's furnace; but, by comparing these only with others made at other times on the sun, discrepant results appear also. Were we, however, to compare the sun *directly* with a terrestrial source of high temperature, and bringing them face to face find one giving more heat than the other, there could (with equal emissive powers) be no question but that the body radiating more heat was also the higher in temperature. Strange to say, this simple test has never, that I know, been applied to this problem* until in the experiments I am about to describe.

We have in the arts one process which gives what we want ready to hand in the production of a vertically disposed surface of several square feet of a liquid metal, hotter than melted platinum itself. I refer to the Bessemer process now in use in several places in this country, among others at the Edgar Thompson steel-works about twelve miles from Pittsburg. I have received every possible assistance from the managers of this great establishment, and owe my acknowledgments here for their kindness.

As the Bessemer process may be as vaguely known to some as it was till lately to me, I will first briefly describe so much of it as concerns the present purpose.

An enormous egg-shaped vessel called the "Converter," capable of holding 30,000 to 40,000 pounds of melted metal, is swung on trunnions so that it can be raised by an engine to a vertical position, or lowered so as to pour its contents into a caldron. First, the empty "converter" is inclined, and into its mouth is poured about 15,000 pounds of fluid pig-iron, whose temperature as it flows in from an adjacent furnace, where it has previously been melted, is about 1400° C. Then the "converter" is lifted to an erect position, and an air-blast from a powerful blowing-engine is forced up through its liquid con-

* Experiments with the lime and electric lights made for other purposes are not here in question.

tents. In the 15,000 pounds of impure iron there are ordinarily found about 230 pounds of silicon and 540 of carbon; and as each pound of carbon gives 8000 calories, and each pound of silicon 12,000 to 14,000, in connection with the air-blast's unlimited supply of oxygen, the temperature of the already molten metal rapidly rises under this enormous inflow of several million calories of heat. After the blast has continued eighteen to twenty minutes, the temperature of the contents is from 1800° to 2000° C., or higher than that of melted platinum, taking the lowest estimate; and now the "converter" is again lowered, and about 1500 pounds more of melted iron added. The temperature here perhaps falls slightly, but its effect may be judged by any one who sees this second lot of iron poured in. Melted iron by itself, every one knows, seems dazzlingly bright; but as this streams into the open mouth, the interior is so much brighter still, that the stream is deep-brown by comparison, presenting a contrast like that of dark coffee poured into a white cup. The contents are now no longer iron, but liquid steel ready for pouring into the caldron; and, looking from in front into the inclined vessel, we see the almost blindingly bright interior dripping with the drainage of the metal running down its sides, so that the circular mouth, which is twenty-four inches in diameter, presents the effect of a disk of molten metal of that size, were it possible to maintain such a disk in a vertical position. In addition, we have the actual stream of falling metal which continues nearly a minute, and presents an area of some square feet. The shower of scintillations from this liquid cataract of what seems at first "sun-like" brilliancy, and the immense area whence such intense heat and light are for a brief time radiated, make the spectacle a most striking one.

Platinum dipped in the steel as it pours from the lip melts away; and not to rely on this evidence, which might be alleged to be due to an alloying rather than a true melting, I procured some platinum wire which Mr. Preusser, the chemist of the works, stretched at my request across the open mouth of the "converter" when in an erect position. The platinum, here several yards above the metal, was melted by the blast which came from it.

Heat Comparisons.

After many visits to the works, much trouble and repeated failures due to the difficulties of working in such novel circumstances, I secured a series of trustworthy measures, in May last, both of heat and light.

I describe my apparatus here in principle, not in detail; and I omit many preliminary experiments, as well as some minute corrections applied for small instrumental errors, giving my results in general terms. One difficulty attending a simultaneous comparison was to obtain a station looking into the "converter" at the time it was inclined and pouring, and yet necessarily outside the building in the sun-light. To do this, I stood in a window (whence the sash had been removed) of the west wall, sixty-one feet from the "converter" mouth. A platform was erected here for my apparatus, part of which was clamped to the wall itself; but though this was the best point of observation, the noise, the shower of sparks driven over the instruments from within by the blast at each "pour," and the rain of wet soot without which fell thick at times on apparatus and observer from the combined steam and smoke of adjacent chimneys, made the task of observation another thing from what it is in the quiet of a physical cabinet.

From this window-station, a *porte-lumière* reflected the sun's rays, so that traced through the dusty air the beam was seen to enter the "converter" mouth, or fall on the stream which ran from it. In the path of this beam was a cylinder, containing within a double enclosure an Elliott thermopile of forty small elements, similar to that I had used for some years on the sun, and surrounded by all the precautions against air-currents and extraneous influences taught me by experience. The pile exposed both faces at once, one to the furnace, the other to the reflected sunbeam; and a Thompson reflecting galvanometer read by an assistant, and placed at a considerable distance from any moving iron, gave prompt evidence as to which face was hotter.

The angular area, subtended at the pile by the fluid metal, was always many times that subtended by the sun's disk, and there was no lens or medium of any kind (except air) between the "converter" mouth and the pile. Supposing, then, the metal to have only presented a disk equal in angular diameter to that of the sun, if the needle remained stationary, it is plain that each was sending an equal amount of heat, and that any square foot of the solar surface was radiating at least as much heat as a square foot of the metal; for it is obvious that the distances of the two sources have nothing to do with this effect under the given conditions.

The metal area, however, being many times that of the sun, the latter still over-balanced the metal; showing that the sun was actually very much the hotter. Accordingly, there was interposed between the *porte-lumière* and the pile a telescope which diffused the sun-light

over an image of any given diameter. As the solar light entered only through a diaphragm of known dimensions, it was easy to say how much the sun's heat was weakened to balance that from the metal. It must be borne in mind, however, that there was no account taken of the loss of solar heat by reflection and absorption in the lenses, by reflection from the mirror, and more than all by the frequent clouds of smoke and steam, while the furnace heat suffered no diminution whatever. Further, every other condition of the experiment was designedly such as to weigh in favor of the furnace and against the sun's heat. The value found for the latter, then, is a minimum value. I should perhaps have remarked that experiments had shown that the trifling heat from objects near the melted metal might be neglected. That from the atmosphere about the sun was also insignificant. Except, then, for the diminution of solar heat by absorption, reflection, and so on, our method is equivalent to bringing a specimen piece from the sun's surface (if I may so express myself) face to face with one from the furnace, placing our thermopile mid-way between them, and determining how much we have to diminish the size of the former to make its heat-radiation no more than equal the latter's.

The result of these experiments was that the minimum value we can assign to the solar radiation is eighty-seven times that from an equal area of the pouring metal. This, it will be remembered, is not an actual but a minimum value. The true value may be indefinitely greater.

Part Second.

Photometric Comparisons.

Of the complex radiations from any source of high temperature, a part is interpreted by the pile as heat, a part by the eye as light; but as the temperature is raised, it is now well known that the waves of shorter length increase in amplitude much faster than the longer ones. If the temperature of the sun, then, be much greater than that of the furnace, we shall have a quite independent proof of the fact in a photometric comparison, which, we can safely pronounce *a priori*, will then give a very much greater ratio of sunlight to furnace-light than that of sun-heat to furnace-heat. To make this comparison, a photometer box, about 8 inches in square section and 66 inches in length, is placed so that its central axis lies as before in the path of the reflected beam from the mirror to the furnace. Two similar

telescopes of 1.66 inch aperture and 20.01 inches focus, having their objectives outside the extremities of the box and their optical axes in the path of the beam, project, by their eye-pieces, images of the sun and of the pouring metal on the two sides of a Bunsen disk, whose normal position is in the centre of the box. Both images are viewed simultaneously by mirrors attached to the disk, which is movable along a graduated scale. (I here omit certain small corrections applied in practice, and describe the use of the instrument in brief terms.) We do not now need to consider the relative angular areas of the sun and furnace, for so long as both are of appreciable size the images of both falling on the screen, when nearly midway between the two telescopes, will be sensibly proportioned in brightness to the absolute intensities of the sun-light and furnace-light. We do in fact, however, at the outset find the sunlight so immensely brighter that no direct comparison is possible. We then diminish the aperture of the solar telescope (which we will call A), till it has a small known ratio to that of the furnace telescope (which we will call B). In practice B was always left with the full aperture of 1.66 inch diameter, while that of A was 0.192. Were the original sources of equal intensity, the sunlight would have been reduced to $\left(\frac{0.192}{1.660}\right)^2 = 0.013 +$ or a little over one one-hundredth of the other. But it was surprising to see that the image from A was even now incomparably stronger than that formed either by the flame from the blast at its brightest, or by the pouring metal. Under these circumstances, the Bunsen disk was moved from its central position toward B, thus approaching the apex of one light cone and withdrawing from the other, so as to diminish the sunlight still further in an exactly determinable ratio. The lowest value obtained in a series of accordant measures gave intensity of sunlight over (5300) five thousand and three hundred times that from the metal; and this value is, I think, considerably below the truth.

It results from these experiments: (1) That direct observation disproves the statement that the sun's effective temperature does not exceed 1500° C. It is demonstrably over 1800° C., and may for any thing here shown to the contrary be indefinitely greater.

(2) The solar heat-radiation, so far from being comparable to furnace heat, is at a minimum something like 100 times that from melted platinum, area for area, and probably much greater.

(3) The solar-light radiation (which offers a more trustworthy indication of the total difference between the sum of all degrees of radiant energy than the heat) is over 5300 times that from a temperature above that of melted platinum.

(4) Since all the above results are simple statements of the facts of experiment, and are independent of formulas, we conclude that the formula of Dulong and Petit (which from well-conducted experiments, like those of M. Violle, deduces conclusions which trial disproves) must be itself wrong. Further, since this formula contains no term depending on the wave-length, it takes no account of the difference here proved to exist between the relative quantities of heat and light radiation from sources of high temperature, and is thus found especially untrustworthy at those temperatures at which it has been most frequently applied.

I do not yet venture an opinion of my own on the real temperature of the sun, further than that I think it much higher than has been of late believed.

The preceding observations and inferences all seem to point to the use of the highest attainable terrestrial temperatures (*e. g.* that of the electric light) in comparisons (and the consequent least dependance on formulas) as the safest line for future investigation.

INVESTIGATIONS ON LIGHT AND HEAT, made and published wholly or in part with appropriation from the RUMFORD FUND.

VIII.

ON THE HEAT PRODUCED BY THE RAPID MAGNETIZATION AND DEMAGNETIZATION OF THE MAGNETIC METALS.

BY JOHN TROWBRIDGE, S.D.,
Harvard University.

AND

WALTER N. HILL, S.B., Harvard University,
U. S. Torpedo Station, Newport, R.I.

Presented, Dec. 11, 1878.

THE fact that iron and steel become heated when rapidly magnetized and demagnetized, has long been known. It is, perhaps, one of the most significant facts in the subject of magnetism; for it is an outward manifestation of the inner work that is done among the molecules when they are endowed and then suddenly deprived of the state which we call magnetism. It gives color to the theory that each particle of iron is given a polarity, and also is twisted or strained in its bed, or caused to vibrate; and brings the subject of the magnetic state of metals into the domain of mechanics, instead of relegating it to the theory of fluids. When we magnetize a bar of steel, the magnet with which we magnetize is not sensibly altered, — it has the same strength as before, — while the piece of steel has been endowed with a new property. How is the doctrine of the conservation of force satisfied? The resulting magnetic state in the piece of steel is not the equivalent of the mechanical motion which the hand gives to the stroking magnet; for it is not necessary to move the magnet. The piece of steel can be left in contact with the poles of the magnetizing magnet. We are forced to conclude that the particles of the steel have been forced into a state of strain, in which the mechanical properties, such as elasticity and viscosity, are involved; and, when we deprive a piece of steel of this mechanical condition, we heat it, just as we can heat a rod of glass or of steel, by stroking it with a cloth covered with resin, and thereby setting it into longitudinal vibration. The rod of glass or steel gives forth a musical note when thus set into longitudinal vibration.

The rod of iron or steel, also, when rapidly magnetized and demagnetized, gives forth a musical note.

Owing to the great kindness of Mr. Joseph Wharton, of Philadelphia, who had provided us with fine specimens of nickel and cobalt bars of his manufacture, and to the courtesy of the officers of the United States Torpedo Station at Newport in allowing us the use of a Wilde's alternating dynamo-electric engine, we were enabled to make the following experiments upon the rapid magnetization and demagnetization of the magnetic metals, iron, steel, cobalt, and nickel.

To measure the strength of the current produced by the dynamo-electric machine, we made use of an electrodynamometer similar to that described in Maxwell's "Electricity" which was constructed on the Helmholtz Gaugain principle both in the fixed and movable coils, and had a resistance of 58.93 of an ohm. The movable coil was suspended from a graduated circle, which read, by means of verniers, to one minute. This circle, however, was only used as a check upon the readings given by a mirror placed upon the movable coils. The telescope and scale were placed seven feet from the mirror. The electrodynamometer was provided with a shunt of one tenth of an ohm, made out of broad ribbons of German silver, the resistance of which did not alter perceptibly during our experiments. Three coarse wire coils of resistances

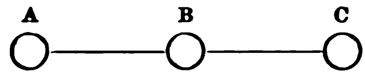
A	B	C
.362	.316	.323

were provided with glass tubes filled with water, which were carefully placed so as not to conduct heat from the coils surrounding them. The bars of cobalt, nickel, iron, and steel, were all of the same size, viz.: —

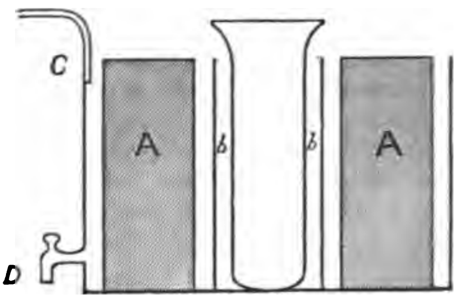
length, 15.15 cm. diameter, 1.25 cm.

Three thermometers, made by Geissler of Bonn, were used, and their readings were subsequently carefully compared with those of a standard Centigrade thermometer, the graduation of which had a probable error of one hundredth of a degree. For this thermometer we were indebted to Professor H. B. Hill, Harvard University. The coils and the thermometers were used in alternation; and the experiments were combined so as to give as many experimental equations as were possible in the short time to which the experiments were necessarily limited on account of the rapid heating of the circuit, and also of the rapid rise of temperature of the water in which the magnetic metals were immersed.

The order of the experiment was as follows: —



In A, B, and C, were placed glass tubes which contained equal volumes of water. Each tube was provided with a thermometer, which was designated by a number engraved upon it. In A, no metals were placed; and the thermometer in this tube consequently gave the change of temperature which resulted from the heating of the coils by the passage of the electric current. Subsequently, we devised an arrangement shown in the accompanying figure. Fig. 1 is a section. The vessel was made of tin with a cylindrical hole in which was placed the



glass tube; and the space *b*, Fig. 1, around it, was packed with infusorial earth. A current of water entered at C, Fig. 1, and passed out at D. A represents a section of the coil. This arrangement, however, was not used; for we found that, by limiting the experiments to a short time, no appreciable error resulted from the heating of the coils themselves. Our object was only to observe the rise of temperature in a given time, that of one minute. In the following table, the temperature readings in Centigrade degrees are given from the tubes placed in the coils A, B, and C. At the head of the columns B and C are placed the names of the metals employed. The temperatures were taken before and after the experiments.

(1)

Water. A			Cobalt. B			Iron. C		
C°		Diff.	C°		Diff.	C°		Diff.
Before.	After.		Before.	After.		Before.	After.	
16.33	16.33	0	16.61	22.97	6.36	16.56	23.40	6.84

Resistance of the circuit, 2.64 ohms.

Current in Vebers, before metals were placed in coils . .	23.57
„ after „ „ . .	19.20
Difference	4.37

Mechanical equivalent = 5144.2 metre grammes.

No. of reversals of magnetization per minute 5844

(2) Water. Cobalt. Nickel.

Water C° Before.	Water C° After.	Diff.	Cobalt C° Before.	Cobalt C° After.	Diff.	Nickel C° Before.	Nickel C° After.	Diff.
16.14	17.04	.90	16.56	23.45	6.89	16.61	21.08	4.47

Resistance of circuit, 2.64 ohms.

Current in Vebers, before metals were placed in coils . .	24.54
„ after „ „ . .	21.34
Difference	3.20

Mechanical equivalent = 2758.5 metre grammes.

No. of reversals of magnetization per minute 5904

(3) Water. Iron.

Water C° Before.	Water C° After.	Difference.	Iron C° Before.	Iron C° After.	Difference.
16.14	17.04	.90	18.51	26.35	7.84

Resistance of circuit, 2.64 ohms.

Current in Vebers, before metals were placed in coils . .	24.544
„ after „ „ . .	21.715
Difference	28.29

Mechanical equivalent = 2112. metre grammes.

No. of reversals of magnetization per minute 5700

(4) Water. Cobalt.

Water C° Before.	Water C° After.	Difference.	Cobalt C° Before.	Cobalt C° After.	Difference.
16.33	18.51	2.18	18.51	26.35	7.84

Resistance of circuit, 2.64 ohms.

Current in Vebers, before metal was placed in coil . . . 23.97
" after " " . . . 21.715

Difference 2.255

Mechanical equivalent = 1363.1 metre grammes.
No. of reversals of magnetization per minute 5880

(5) Water. Nickel. Steel.

Water C° Before.	Water C° After.	Diff.	Nickel C° Before.	Nickel C° After.	Diff.	Steel C° Before.	Steel C° After.	Diff.
16.14	16.80	.66	16.86	21.60	4.74	17.04	28.02	10.98

Resistance of circuit, 2.64 ohms.

Current in Vebers, before metals were placed in coils . . 24.355
" after " " . . 20.208

Difference 4.147

Mechanical equivalent = 4528.3 metre grammes.
No. of reversals of magnetization per minute 5784

Practically, the same result was given when a bar of steel was substituted for the iron.

(6) Water. Nickel.

Water C° Before.	Water C° After.	Difference.	Nickel C° Before.	Nickel C° After.	Difference.
16.80	19.22	2.42	16.56	21.79	5.23

Resistance of circuit, 2.64 ohms.

Current in Vebers, before metals were placed in coils . . 24.169
„ after „ „ . . 22.848

Difference 8.321

Mechanical equivalent = 455.2 metre grammes.

No. of reversals of magnetization per minute 5808

The following table exhibits the work done, expressed in metre grammes, in magnetizing and demagnetizing equal volumes of the metals in one minute:—

Metals.	Metre grammes.	No. of reversals in one minute.
Iron	2112.	5,700
Cobalt	1363.1	5,880
Nickel	455.2	5,808
Cobalt and Iron . . .	5144.2	5,844
Cobalt and Nickel . . .	2758.5	5,904
Nickel and Steel . . .	4528.3	5,784

The electrical measurements contained in the above tables consisted in deducing the current in Vebers from the deflections of the movable coil of the electrodynamometer, which was placed in the magnetic meridian. The expression for the current is

$$C = \sqrt{\frac{F}{Gg}\tan\theta}$$

Where F is directive force of bifilar suspension.

G and g constants of fixed and movable coils.

In the instrument used, the value of $\frac{F}{Gg}$ was 10.4

The resistance of the circuit was measured as accurately as possible. The variations in the current were undoubtedly due to the heating of the machine itself. It was to be regretted that we were not enabled to measure the resistance of the circuit more accurately. This was impossible, under the conditions of the experiments. The mechanical equivalent of the current consumed in heating the metals was deduced from the expression

$$W = \text{work} = C^2Rt.$$

The current 1 Veber in a conductor of resistance one ohm = $1.000000 \times 10^6 \frac{mm^2.mgr.}{sec^3}$. Which reduced to the unit of work is equal to $\frac{1.000000 \times 10^6}{9806 \times 10^6} = 102.$ metre grammes.

The analyses of the cobalt and nickel were as follows: —

Nickel 1. 3.1328 grammes gave 0.0115 gramme Fe_2O_3.
0.0115 gramme Fe_2O_3 = .00805 Fe = 0.256 %.

Nickel 2. 4.3002 grammes gave 0.0178 gramme Fe_2O_3.
0.0178 gramme Fe_2O_3 = 0.01246 Fe = 0.289 %.

Cobalt 1. 4.2264 grammes gave 0.0492 gramme Fe_2O_3.
0.0492 gramme Fe_2O_3 = 0.03444 gramme Fe_2 = 0.814 %.

Cobalt 2. 4.5606 grammes gave 0.0358 gramme Fe_2O_3.
0.0358 gramme Fe_2O_3 = 0.02506 gramme Fe = 0.55 %.

Cobalt 3. 3.3940 grammes gave 0.1091 gramme Ni O.
0.1091 gramme Ni O = 0.08571 gramme Ni = 2.52 %.

The weight of bar of cobalt was 163 grammes approximate.
" " nickel " 159 grammes approximate.

The bars of nickel, cobalt, iron, and steel, all emitted loud musical notes while in the process of being magnetized and demagnetized, the note emitted by the iron being the loudest. These notes could easily be heard two hundred feet away from the bars.

Among the papers published on the magnetic metals is one by Professor Barrett of the Royal College of Science, Dublin, which is entitled "The Molecular Changes that accompany the Magnetization of Iron, Nickel, and Cobalt." After giving a *résumé* of what has been written on this subject, the author remarks: "Nickel is invariably ranked above cobalt in the scale of magnetic metals, Faraday and others placing it next to soft iron. But the bar of nickel I have used, when submitted to the same magnetizing current as the cobalt bar, exhibits far less portative force than the cobalt. It is remarkable that the iron impurity contained in the cobalt is able to produce so powerful an influence. The nickel, like other specimens I have met with, has a very slight retentive power when magnetized; whereas, the cobalt has a high degree of coercive force."

It appears from our result that it is not the iron in the cobalt which produces the high amount of molecular heating noticed by us; for the chemical analyses showed an amount of iron which would be inappreciable in the electrodynamic experiments.

The following table, for which we are indebted to a paper by Professor W. F. Barrett, published in the London "Philosophical Magazine," 1873, Vol. XLVI. page 478, exhibits the relationship of the magnetic metals: —

Substance.	Density. Water = 1.	Atomic Weight H = 1.	Specific Heat. Water = 1.	Atomic Heat.	Dilatation		Conductibility		Tenacity and Melting Point.
					by Heat.	by Strain.	for heat. Silver. = 1.	for sound. Air = 1.	
Iron. .	7.8	56.0	0.1138	6.38	.0926	.0387	.168	15.3	Very high.
Nickel	8.3	58.5	0.1091	6.33	.0899	.0394	.131	14.9	"
Cobalt	8.5	58.5	0.1070	6.26	.0981	.0436	.172	14.2	"

Our results show that in regard to molecular heating, so to speak, by magnetizing and demagnetizing, cobalt stands very close to iron, while nickel is far removed from it.

Recapitulation.

1. It appears from the preceding experiment that the rapid magnetization and demagnetization of iron, steel, cobalt, nickel, is accompanied by a marked rise in temperature.

2. Under the same conditions, this rise in temperature is greatest for iron and least for nickel.

3. The rise in temperature of cobalt in some cases may be as much as that of an equal volume of iron.

4. The rise in temperature of the magnetic metals submitted to this process is accompanied by a marked increase of work done by the electrical circuit, which can be readily measured by an electrodynamometer.

5. The magnetic metals submitted to the above process severally emit loud musical notes, which rank in the following order: iron, cobalt, and nickel.

INVESTIGATIONS ON LIGHT AND HEAT, made and published wholly or in part with appropriation from the RUMFORD FUND.

IX.

METHODS OF MEASURING ELECTRIC CURRENTS OF GREAT STRENGTH; TOGETHER WITH A COMPARISON OF THE WILDE, THE GRAMME, AND THE SIEMEN'S MACHINES.

BY JOHN TROWBRIDGE, *Harvard University*.

Presented, Oct. 9th, 1878.

THE measurement of electric currents of great strength can be classed under four heads: No. 1. The Galvanometric Method. No. 2. The Electrometer Method. No. 3. The Heat Method. No. 4. The Electrodynamometer Method.

No. 1. *The Galvanometric Method.*

With a galvanometer of small resistance and of large radius, it is necessary to bring the deflection to the neighborhood of 45° by means of a shunt of very small resistance. The errors increase when the deflections exceed 45° in a divided circuit, and, by the use of a shunt of small resistance, any error in the measurement of this small resistance multiplies the whole observation by this error.

By the use of a cosine galvanometer which I devised in 1871, and published in the "American Journal for Science" for that year, the use of shunts can be modified; but there are difficulties from the dip of the needle and from want of accuracy in graduations of the circle which measures the deflection of the moving coil from the vertical plane.

In practice, it is very inconvenient to find a suitable shunt which will answer for a wide range of experiments, and different shunts have to be used. Moreover, the heating of the shunt multiplies the observations by an error. In short, by the use of a shunt method, we measure a large quantity by observations upon a hundredth or a thousandth part of itself, and proceed from a small quantity to a large one which is a fundamentally defective method.

No. 2. *The Electrometer Method.*

By means of a suitable electrometer, the difference of potential of two points in a closed circuit can be measured; and, from this, the electromotive force in volts can be estimated. The difficulty of dealing

with static electricity in electrical measurements is well known. Leakage, want of constancy of charge in the electrometer, nay, impossibility of maintaining a charge in certain localities, limit the use of this method, even if the results obtained were not approximate.

No. 3. *Heat Method.*

By the use of the law that the heat developed in a circuit is expressed by $H = C^2Rt$, where C is current in Vebers, R = resistance, t = time, we can deduce C by measuring the rise of temperature of a given volume of water. Measurements of temperature are especially fraught with difficulties on account of conduction, radiation, and errors of thermometers, beside consuming time in waiting for the proper conditions for a given experiment.

No. 4. *The Electrodynamometer Method.*

The principle of Webers' electrodynamometer is well known. The electric current passes down one wire of the bifilar suspension of a movable coil and up the other, and then through fixed coils surrounding the movable coil. Maxwell, in his "Electricity and Magnetism," Vol. II. p. 332, remarks: "Webers' form of the electrodynamometer, in which one coil is suspended within another, and is acted on by a couple tending to turn it about a vertical axis, is probably the best fitted for absolute measurements." With powerful currents, however, it is necessary to shunt this instrument, and the errors inherent in this method are introduced. Even with moderate currents, the directive force of the bifilar suspension is changed by the elongation of the wire from a rise in temperature. If we keep within the point at which the wires are elongated, the deflections are slight and subject to error of observation.

In working with dynamo-electric machines, it is important that we should avoid the method of shunts; for the entire resistance of the circuit is generally of the same order of magnitude as the shunts employed. It is necessary that we measure the whole strength of the current directly at the same time that we measure the work consumed in driving the dynamo-electric machine, the velocity of the machine, and the resistance of the circuit. It is also important to eliminate local attractions. The time consumed in measuring the current strength should be small.

The instrument described in this paper fulfilled the conditions prescribed.

Fig. 1 shows the general aspect of the apparatus. The large fixed coils were made of copper bands, 35 mm. broad and 1 mm. thick.

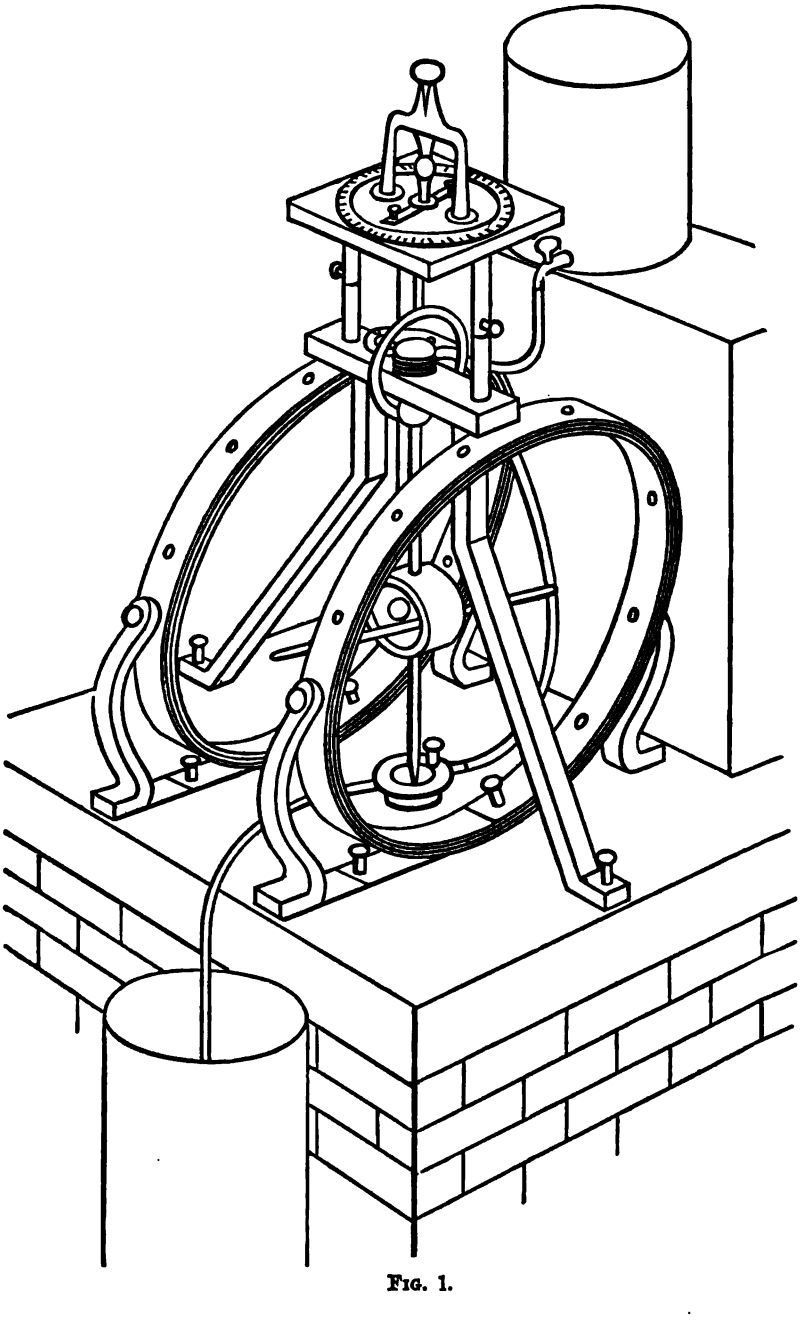


Fig. 1.

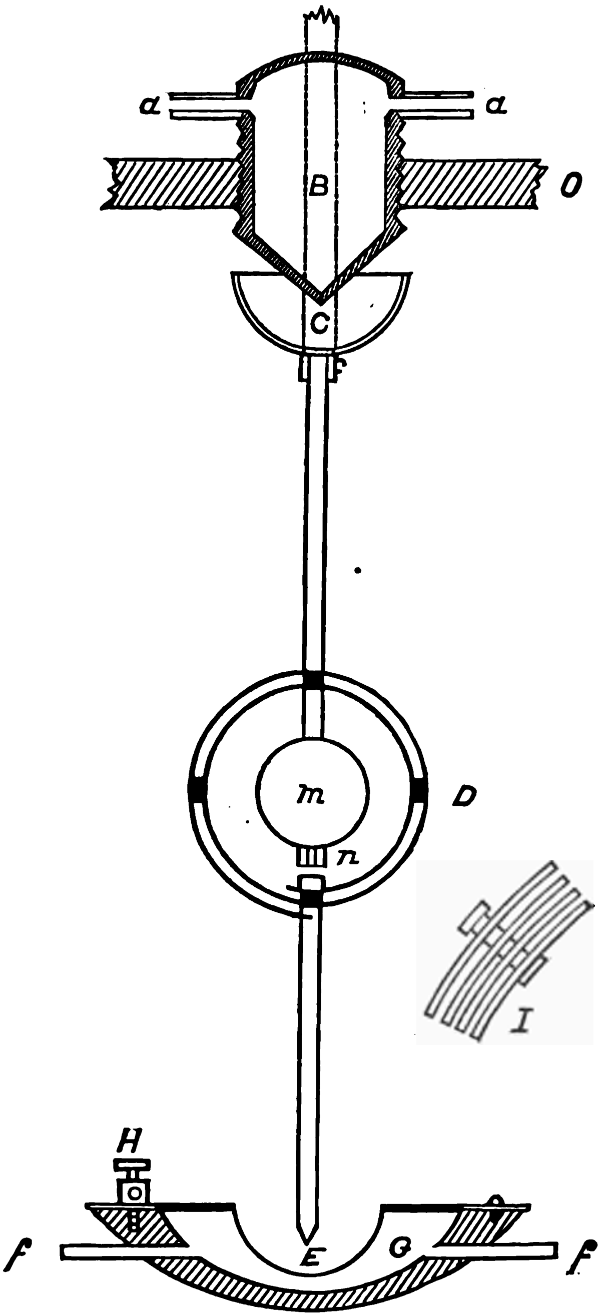


FIG. 2.

There were twelve coils, six on each side of the movable coil which is shown with its suspension between them. The large coils were insulated from each other by vulcanite washers, and held together by brass rivets which were insulated by vulcanite cylinders. The coils were placed at a distance apart equal to their thickness, and thus allowed currents of air to pass freely between them. This arrangement is shown at I, Fig. 2. The bifilar suspension is connected with a graduated circle which read by means of verniers to one minute. The tangent and clamping screws of the torsion head are not shown in the figure. The general arrangement was similar to that used by Mr. Latimer Clark, and figured in Maxwell's "Electricity," with the exception that the graduation was not upon a cylinder, but was on a plane, and the graduated circle was such as is used on spectrometers. The torsion head admitted of vertical adjustment by means of the hollow cylinders at its points of support, in addition to the vertical adjustment of the pulley by means of which the tension upon the suspending threads was equalized. In the ordinary form of electrodynamometer, the current passes down one suspending wire and up the other. In my dynamometer, this is not the case, as is shown in Fig. 2. Therefore, the suspension can be made of strands of silk or any suitable material, according to the sensitiveness desired. In the actual use of the instrument with powerful current, it was found necessary to use steel wire in order to increase the directive force, so great were the deflections.

The movable parts are best shown in Fig. 2. The construction of the central coil is shown at D. The water enters at *a*, passes out at *a* after cooling the hollow chamber B, which admits of adjustment, and then flows by rubber tubing to *f*; and, after cooling the mercury cup E, flows out through *f*. G is the water-chamber which answers to B. At *n*, below the mirror *m*, is a bar upon which are hung cylindrical weights to determine the moment of inertion to alter the sensitiveness. Only one coil and a half are shown in the figure. The electric current enters at H, passes through the mercury cup to E, then to C, and thence by the hollow cup to O, and then around the outer coils.

A telescope with scale was employed to read the deflections; but it was found better, in practice, to use the graduated circle of the torsion head and bring the movable coil back to zero. In this case, we have from the theory of the electrodynamometer: —

$$C^2 = \sqrt{\frac{F}{Gg}} \sin \theta ;$$

and the effect of the earth and local attraction are eliminated. By this method of observation, no telescope and scale are needed. It is only necessary to bring the point of the bar which passes through the movable coil to a fixed point. The mercury in the pivot cups serves to dampen the vibrations of the movable part of the apparatus; and it was found that readings could be taken quicker than by galvanometric methods.

Theory of Instrument.

("*Maxwell's Electricity*," *Vol. II. page* 829.)

$$C^2 = \frac{F \tan \theta.}{Gg \cos \beta.}$$

Where

$C =$ current.

$F =$ directive force.

G and $g =$ constants of fixed and movable coils.

$\beta =$ angle of coil with magnetic meridian.

If the torsion head of the instrument can be adjusted so that the deflection is zero, and $\theta = -\beta$

$$\text{we have } C^2 = \frac{F}{Gg} \sin \beta.$$

The value of F was determined by several methods. Since

$$Ft^2 = \pi^2 A,$$

where t is time of vibration,
and $A =$ moment of inertia,

it is necessary to determine both the time of swing and the inertia. The times of swinging were obtained by means of a chronograph upon which seconds were recorded by the side of the records produced by breaking an electric circuit at the instant the movable coil passed the middle of its vibrations. The moment of inertia was first determined experimentally by adding known cylindrical weights, and determining the new time of vibration.

We thus have

$$A = k\left(\frac{t^2}{(1 + \frac{w}{w_1})\, t_1^2 - t^2}\right)$$

$$\text{and } k = w\left(l^2 + \frac{r^2}{2}\right)$$

where $k =$ moment of inertia of added cylindrical weights; $w =$ weight of cylinders in milligrammes; $l =$ distance of point of suspen-

sion of cylinders from axis; $r =$ radius of cylinders; and w, mass of moving parts before w was added. The dimensions being in millimetres.

From these expressions, we obtain

$$F = \frac{\pi^2 k}{\left(1 + \frac{w}{w_1}\right) t_1^2 - t^2}$$

The constants G and g were calculated from the actual measurements of the coils, which could be made with great accuracy, since all the parts were large.

The constants were as follows: —

$$\text{mean radius } r = 153.3 \text{ mm.}$$
$$Gg = 1631.45$$
$$\frac{F}{Gg} = 656.626.$$

The constant was also determined by the running the same current through the electrodynamometer and a tangent galvanometer of one turn of copper wire, whose radius was r and whose constant was equal to $\frac{rT}{2n\pi}$.

In this case $C^2 = \frac{r^2 T^2}{4n^2\pi^2} \tan^2 \theta = \frac{F}{Gg} \sin \varphi$, and $\frac{F}{Gg} = \frac{r^2 T^2}{4n^2\pi^2} \cdot \frac{\tan^2 \theta}{\sin \varphi}$,

where $T =$ horizontal form of earth's magnetism.
$r =$ radius of galvanometer coil.
$\theta =$ deflection of galvanometer.
$\varphi =$ deflection of electrodynamometer.

The result obtained in this way closely agreed with that obtained by the previous method.

No difficulty was experienced from the heating produced by currents of even eighty vebers, when the current was allowed to run for a long period through the instrument; as long as the stream of water was maintained around the mercury cups, even a small immersion of the points of the axis of the movable part of the instrument did not result in heating. By this instrument, therefore, the whole current could be measured without shunting. At first, the metal pivots which dipped into the mercury were tipped with aluminum; but, when a strong current passed through them, the mercury was disturbed by an apparent ebullition, and the mercury speedily was covered with a black deposit. It was found that copper points would answer perfectly well. Dis-

tilled mercury was used in all cases: it answered the double purpose of conducting the current and bringing the vibrations quickly to rest.

Through the courtesy of Captain Breese, U. S. N., in charge of the U. S. Torpedo Station at Newport, R. I., who obtained permission for me to use the dynamo-electric engines at that place, I was enabled to make a series of measurements with the dynamometer described above.

The resistances used consisted of large bands of german silver, each in the neighborhood of $\frac{1}{10}$ of an ohm resistance. The foot-pounds of work consumed were measured by a Batchelder's dynamometer,* which is fully described in Dingler's "Polytechnic Journal," 1844, Vol. II. This dynamometer is not suitable for the measurement of small or great horse-power; but it answered very well in the limits of velocities and horse-powers to which I confined myself. An accurate measure of the work consumed in running a dynamo-electric machine upon a closed circuit would require the use of gearing instead of belting; for it is difficult to estimate the slip of the belting. On account of the error introduced from this latter-mentioned clause, I have given the whole work required to run each machine on a closed circuit. The slip on an open circuit would be small, but on a closed circuit might be very large. The machines were run under the same conditions of shafting and pulleys. It was estimated that the Siemens required 0.031 horse-power on an open circuit, and the Gramme 0.206 to 0.328 horse-power. The term efficiency denotes the ratio of the equivalent in metre grammes of the current produced to the metre grammes consumed in running the dynamo-electric machine. Since one veber through one ohm

$$= C = \frac{10^5}{10^7} = 10^{-2}$$

the work $w = C^2Rt = (10^{-2})^2 \times 10^7 = 10^3 = 1000$ units of work, and dividing by the unit employed we have

$$\text{equivalent of 1 Veber} = 102 \text{ metre grammes,}$$
$$\text{one foot-pound} = 138 \text{ metre grammes.}$$

* For which I am indebted to the Massachusetts Institute of Technology.

WILDE MACHINE (*large size*).

Resistance of circuit in ohms.	Current in Vebers per sec.	Speed of machine per min.	Metre grammes consumed per sec.	Equivalent of current in metre grammes per sec.
.594	62.83	548	350.658	235.480
.788	61.76	508	392.408	285.293
.857	43.82	532	283.107	167.907
.907	60.25	500	458.128	835-966
1.039	39.28	520	298.356	163.682
1.120	43.44	548	343.827	215.660
1.241	50.43	504	542.685	322.047
1.453	44.94	520	553.311	309.658
1.598	47.51	536	688.765	366.910
2.305	32.86	528	643.632	253.968

The measurements with the Wilde machine were made with an electrodynamometer similar to that described in Maxwell's "Electricity and Magnetism." It was constructed on the Helmholtz Gaugain principle, and had a resistance of 58.9 ohms. A shunt of .1 ohm had to be employed, and the instrument was also coupled in multiple arc to avoid the lengthening of the bifilar suspension.

GRAMME MACHINE (*large size*).

Resistance of circuit in ohms.	Current in Vebers per sec.	No. of revolutions of armature per min.	Metre grammes consumed per sec.	Equivalent of current in metre grammes per sec.
.675	86.0	432	589.743	509.418
.760	75.6	462	534.336	442.211
.781	75.6	452	607.200	455.377

SIEMENS MACHINE (*large size*).

Resistance of circuit in ohms.	Current in Vebers per sec.	No. of revolutions of armature per min.	Metre grammes consumed per sec.	Equivalent of current in metre grammes per sec.
.973	79.8	264.	831.105	632.255
1.055	68.8	294.5	743.820	509.569
1.066	66.0	325.	889.454	472.805

I add a few data in regard to the dimensions of these machines, which are partly taken from the reports of the Secretary of the Navy for 1877, and partly from the Station records which were generously placed at my disposal.

The Gramme Machine.—This machine weighs about 2,700 pounds, stands 30″ high, is 40″ long and 34″ wide. It is driven by a pulley 15″ in diameter. The armature moves with very little friction. The field of force coils are flat, and there are four of these, each about 10″ long, 3¾″ deep, and 22″ wide. The armature resistance is 0.129 ohms, the field resistance 0.212 ohms; thus making .341 ohms for the total internal resistance. The total weight of wire in the machine is 483 pounds; or the weight of wire is nearly 18 per cent of the total weight of the machine.

Siemens Machine, or Heffner von Altenek Machine, built by the Siemens Bros. This machine is 61″ in length, 28″ in breadth, and 12″ in height. The armature is nearly 34″ long, and 9⅓″ external diameter. It is formed by winding 98 pounds of two insulated wires longitudinally, and in eight divisions, around a thin and hollow brass cylinder. Within this hollow cylinder is a hollow stationary cylinder of cast iron, supported by bearings that pass through the brass cylinder. The commutator has eight divisions, which are eight sector-shaped sheets of brass insulated from, but attached to, the face of a plate which is outside of one of the bearings of the brass cylinder. Two collectors or brushes trail upon and press against these sectors: these brushes have a bearing so extensive as to short circuit or bridge over the edge of two sectors. The spark of the commutator is quite insignificant. This machine differs from all others in this respect: the armature simply moves a wire through a field of force, and not a soft iron core covered with wire. The resistance of the entire circuit, field of force, connected for conductivity, is .586 ohms. The normal velocity of machine is from 370 to 380 revolutions per minute.

Wilde Machine.—"This resembles, in some respect, the Hjorth machine of 1855, with the permanent magnet omitted. It has two armature circuits: one with current uniform in direction for the purpose of maintaining the magnetism of the field; and the other for producing the electric light. The current from this last circuit is a to and fro current, without commutator.

"The armature wire weighs 28 pounds, and is divided into two circuits; about 7 pounds of it having a resistance of .454 ohms furnishes the current which maintains the field. The remainder, 21 pounds, having a resistance of .074 ohms, maintains the to and fro current. About 325 pounds of wire are distributed in 24 coils to make up the electro-magnetic field which has a resistance of 2.83 ohms. These coils are 10½″ in length and 3⅞″ in external diameter, having soft round cores 2″ in diameter. There are 24 armature cores and coils, one half

on each side of a central cast-iron wheel 1½″ thick. The central diameter of this wheel is 18″ nearly. The whole weight of wire in this machine is nearly 354 pounds." The normal velocity of machine is about 600 revolutions. A greater rate of speed would have increased, to a certain extent, the currents produced by the Siemens and the Gramme machines: on the other hand, more horse-power would have been necessary to attain this increased speed. The Wilde machine requires more horse-power to run it, as the resistance of the outside circuit increases. This is due to the construction of the machine, and is not the case with the Siemens and the Gramme machine. A certain proportion between the resistance of the machine and that of the outside circuit is undoubtedly best for greatest efficiency of dynamo-electric machines; and a certain velocity is necessary to attain the greatest efficiency.

From my experiments, I should class the machines as follows: —

Gramme,
Siemens,
Wilde.

Theoretically, the Siemens machine should give the best results. At the time of my experiments, the Siemens machine suffered the disadvantage of being run at a less rate of speed than the other machines.

I hope to pursue these tests under conditions resulting from higher speed. Generally speaking, that machine is the best which gives the greatest efficiency at low rates of speed; for the necessity of high speed introduces much that is detrimental to the locality of the machine and to the machine itself. At the present time, alternating machines are coming into notice again, in connection with electric lighting; and a suitable electrodynamometer is desirable in the measurement of the current produced by these machines. The instrument which I have tested above seems to fulfil the proper conditions.

My thanks are due to the officers of the station for their generous assistance and free disposal of the resources of their electrical department.

X.

DESCRIPTIONS OF SOME NEW SPECIES OF NORTH AMERICAN MOSSES.

BY LEO LESQUEREUX AND THOMAS P. JAMES.

(*With a Supplement by* W. P. SCHIMPER.)

Presented February 12th, 1879.

THE new species of mosses here described have been received by us from various sources since the death of Mr. Sullivant and the publication of the Supplement to the Icones Muscorum. On a recent visit by Mr. James to Europe, he took with him not only specimens of these species, but also of many of those recently described as new in the scientific periodicals of this country, for the purpose of critically re-examining the whole in co-operation with Professor W. P. Schimper, of Strasburg. This justly celebrated bryologist has cordially given his assistance in this review, and therefore secured to the description of our species a higher degree of authority. Our grateful acknowledgments are most cordially offered to him for this service, and also for the communication of the descriptions of some new species of American mosses prepared by himself on specimens derived from the rich and mixed materials of the well-known collections of Drummond.

SPHAGNUM GARBERI. Planta magnitudine et habitu inter *Sphagnum molle* et *Sphagnum squarrosum*, var. *squarrulosum*, ludens, viridis. Caulis mollissimus: indusium corticale e stratis 3 cellularum laxarum compositum; cylindrum internum e cellulis extus minutis intus majoribus leptodermicis omnibus hyalinis compositum.

Folia caulina mediocriter magna deltoideo-ovata, apice subcucullata et subintegra, ad angulos appendiculata integra; cellulis omnibus hyalinis majoribus, versus marginem vix angustatis, basin versus parce fibrosis nec porosis, ad apicem fibrosis et pertusis. Ramuli patentes breves vix incurvati squarroso-foliosi, penduli parum elongati imbricato-foliosi. Folia ramulorum patentium e basi concava imbricante patula valde concava, apice truncato dentata, haud marginata, cellulis

majoribus valde fibrosis, cellulis chlorophyllosis perangustis paulum versus dorsum dispositis omnino vel fere obvelatis poris numerosis.

Flores dioici. Perichætium haud vaginans; folia ascendendo majora, subremota, subfalcata, secunda, elongato-lanceolata, valde concava, pallide viridia, mollia, laxe cellulosa, limbo latiusculo e cellulis angustis elongatis formato, cellulis hyalinis basilaribus maximis sine fibris et poris, superioribus fibrosis et parcius porosis; apice angusto eroso.

Capsulæ in eodem capitulo complures pseudopodio elongato albicante suffultæ parvulæ, rufo-brunneæ. Sporæ luteæ magnæ.

HAB. Florida (*Garber*).

In the disposition of the branches, the color of the plant, the semi-squarrose greenish leaves, and the general facies, this species is similar to *S. humile*, Schimp., as described and figured in Sullivant's Icones, p. 5, tab. 3. Its size is a little smaller, and the capsules longer pedicelled and also smaller. This difference is marked, and renders the species recognizable at first sight. The absence of pores in the areolæ, and the immarginate branch leaves, truncate-dentate at the apex, are also characters which separate this species from *S. humile* and related congeners.

ARCHIDIUM LONGIFOLIUM. Differt ab *Archidio alternifolio* planta tenuiore; foliis angustioribus, longioribus, anguste e lanceolato subulatis; costa superiorum in subulam lævem excedente. Antheridia 2 in foliorum perichætialium axillis.

HAB. Florida (*Garber*).

The longer narrow leaves give this moss an aspect far different from that of *A. alternifolium*, with which it is distantly comparable. The capsule and its spores have the same character.

BRUCHIA FLEXUOSA, Schwægr. Caulis semiuncialis et longior pertenuis. Folia inferiora remota, parvula, media sensim longiora, anguste lanceolato-subulata, e basi erecta patula; summa in comam suberectam conferta, e basi ovato-oblonga concava anguste lanceolato-subulata, summo apice leviter serrata; costa tenui cum vel sub apice evanida; rete basilare laxiusculum hexagono-rectangulum superius angustum.

Flos *bisexualis*. Capsula in pedicello longiore leniter curvato oblonga, longicolla (collo sporangio æquali) in rostellam producta.

HAB. On moist exposed grounds in the Southern States.

BRUCHIA SULLIVANTI, Austin. Caulis perbrevis. Folia suberecta, media e basi brevi-ovata, anguste lanceolata, summa e basi longiore

peranguste lanceolato-subulata; costa in foliis mediis sat valida, in summis ad basin concavam pertenui; reti densiore; foliis omnibus solidioribus.

Flores *monoici*, ♂ gemmiformes. Capsula brevius pedicellata brevior.

B. flexuosa, Sullivant, Icones Muscorum, p. 22, tab. 13.

HAB. On clayey soil, common.

Bruchia nigricans is separated by Austin on account of a difference in the color, larger spores, and longer pedicel. The specimens of the Musci Exsiccati were collected on the top of Raccoon Mountain, in a narrow swampy depression, which was filled with typical *B. Sullivanti*, as distributed in the Musci Exsiccati under the name of *B. flexuosa*. In the centre of the moister portion of this area, the moss was covered with confervoidal filaments, which blackened the plants and so decomposed them that none of all the specimens obtained are entire. We consider therefore this form, upon which *B. nigricans* is based, as only a casual variety.

BRUCHIA BREVICOLLIS. Differt a *Bruchia Sullivanti* planta minore graciliore; foliis pro ratione longioribus, supra basin ad apicem angustioribus, longe subulatis, subula tota e costa dilatata constituta; calyptra majore infra sporangium producta; collo multo breviore angustiore; pedicello recto; sporis majoribus.

HAB. With *B. Sullivanti* in South Carolina (*Ravenel*).

This species and *Bruchia Sullivanti*, Austin, are generally found together, and are separated from *B. flexuosa*, Schwægr., especially by the monœcious inflorescence, the shorter pedicel of the capsule, and the minute spores. The author of *B. flexuosa* had not mentioned the inflorescence. The monœcious character of *B. Sullivanti* was first recognized by Sullivant, in his specification, and afterwards confirmed by James, while *B. flexuosa* is bisexual.

WEISIA LONGISETA. Plantæ magnitudine et habitu illis *Weisiæ viridulæ* similes.

Folia e basi concava oblonga pallida longe lineali-lanceolata, valde concava et margine inflexo subtubulosa, acute apiculata, viridia; costa valida ad apicem producta; reti superiore perangusto chlorophylloso, basilari laxo omnino hyalino.

Flores dioici; masculi in eadem planta complures hic illic aggregati gemmiformes, polyphylli; antheridia sat numerosa, paraphysata.

Capsula in pedicello longo subunciali pertenui subflexuoso lutescente subcernua, ovata, minuta, ferruginea, sicca deoperculata sub ore leniter constricta, longitudinaliter 8-sulcata; peristomii dentes majusculi, per-

fecti lineali-lanceolati, seu in linea divisurali usque infra medium lacunosi seu bifidi et regulariter bicrures, subramuloso-papillosi, siccitate patentes. Sporæ majusculæ ferrugineæ.

HAB. On the ground at Enterprise, Florida (*W. L. Foster*).

The pale green color of the plants, the long slender yellowish and often twisted pedicel, the curved capsule, and the large perfect teeth of the peristome give to this species the appearance of a *Dicranum*. It cannot be taken for a variety of *Weisia viridula*, Brid.

WEISIA WOLFII. Differt a *W. longiseta* foliis angustioribus pro ratione longioribus, parte superiore fere exacte tubulosis, humiditate arcuato-recurvis; capsula in pedicello breviore longiore oblongo-cylindrica, sicca subcylindrica, haud sulcata nec sub ore coarctata; peristomii dentibus truncatis.

Flores dioici, ut in *W. longiseta;* operculum subulirostrum.

HAB. On the ground at Canton, Illinois (*J. Wolf*).

A good species, related to *W. mucronulata*, Schimp., in the shape of its leaves. The capsule is small, rather ovate than cylindrical, the operculum long-beaked, and the pedicel flexuose or sometimes geniculate.

PTYCHOMITRIUM (NOTARISIA) PYGMÆUM. Planta perpusilla, dense foliosa, olivaceo-viridis. Folia humida patentia, sicca subcirrhata, solidiuscula, e basi ovali pallida linealia, mutica obscure viridia, mediocriter concava, lævia; costa sat longe sub apice evanida; reticulum partis superioris chlorophyllo obscuratum perangustum, basilare hyalinum areolis hexagono-rectangulis achlorophyllosis.

Flores monoici; masculi in eadem planta complures, secus femineum vel versus basin dispositi, gemmiformes, fuscescentes; antheridiis parvulis eparaphysatis.

Fructus: calyptra magna usque ad capsulæ basin producta, fusca; capsula in pedicello brevi rufo ovalis, collo tertiam partem sporangii æquante instructa; operculum in rostrum subulatum subrectum productum; annulus latus; peristomii dentes 16 subæquales, basi per paria confluentes, hic illic tota longitudine connati, lineali-subulati papillosi, articulationibus parum distinctis rufi.

HAB. Near the Neosho River, Kansas, and at Bolivar, Missouri (*E. Hall*).

This species, the smallest of the genus, is distinguished by its minute size, the structure of its leaves, — areolation obscure in the upper portion and hyaline-hexagonal at the base, — and the marked neck of the capsule, extending one third its length.

FISSIDENS GARBERI. Planta minutula gregaria obliquata corticola. Folia 4–8 juga, leniter decurva, subelongato-oblonga, superiora quadruplo longiora quam lata, auricula medium circa folium attingente, ala dorsali instructa, lata, versus basin sensim angustata; lamina verticalis parte folii auriculata paululum latior, apice mutica, rarius breviter acuminata, margine papillis in quacunque cellula marginali binatis minutissime crenulata, foliorum vaginulæ circumsitorum marginibus auriculæ e medio ad basin limbo e cellulis majusculis hexagono-rectangulis bi–triseriatis instructis; rete totius folii cæterum minutum hexagono-rotundatum distinctum.

Flos terminalis bisexualis.

Capsula in pedicello assurgente longitudinem plantæ æquante erecta vel suberecta ovalis, pallide fuscescens, ore rubro mollis; peristomii perfecti dentes e basi integra dense trabeculata rufa bicrures, cruribus lutescentibus; operculum magnum rostratum.

HAB. On the bark of trees, Florida (*Garber*).

The plants are mostly simple, rarely dichotomous. This species in the shape of its leaves resembles *F. obtusifolius*, Wils., but it is smaller, the capsule narrower, the operculum beaked, and the areolation rather quadrate than angular-rounded. No. 19 of Wright's second collection of Cuban Mosses in Sullivant's Herbarium includes many specimens (which had been examined and figured, but not named) that correspond with this species, though varying in size, and found on sticks, bark, and stones, as well as on the ground. As other Cuban mosses occur in Florida, it is not remarkable that this species also should have been collected in both localities.

FISSIDENS FLORIDANUS. Planta semiuncialis et subuncialis e basi parce ramosa, inferne fusca, superne læte viridis.

Folia e caulis basi ascendendo majora, dense conferta, superiora lineam fere longa cultriformia, auricula sat longe supra medium producta, apice subtiliter suberoso-denticulata, cæterum integra, limbo latiusculo pallido circumducta; costa sat valida paulum sub apice evanida; reticulo minuto, hexagono, in lamina verticali basi et limbo exceptis angustiore et minus distincto quam in auriculæ alis, lamina dorsali ad folii basin subito fere abrupta, sicca cirrhato-incurva.

Flores monoici; masculi in ramulis lateralibus longiusculis terminales; feminei axillares ad medium caulem dispositi.

Fructus in ramulo perichætiali perbrevi basi radicante ex eodem caule solitarius, rarius binatus; folia perichætialia caulinis pallidiora laxius texta, auricula latiore dorso usque ad medium anguste alata,

subito in laminam verticalem brevem exeuntia; capsula in pedicello semiunciali vel paulo longiore valido rubello cernua, ovali-oblonga; operculo magno longirostro.

HAB. Florida (*Garber*).

In facies, color, and in the size of the plants, this species is like the small forms of *F. osmundoides*, Hedw., to which it is also related by its monœcious terminal inflorescence. The leaves have about the same form; but they are denticulate at the apex, have a reticulation of minute hexagonal areolæ, and the lamina is surrounded with a large pellucid border. The capsule is also longer, subcylindrical, and curved.

CRYPHÆA PENDULA. Plantæ graciliores laxe pendulæ atro-fuscæ superne tantum virentes. Caulis primarius vix ullus brevissimus; rami secundarii filiformes, simplices, medio crassiores, apice tantum divisi; ramis capillaribus, vel duobus simplicibus elongatis vel plurimis brevibus, flagellatim dispositis.

Folia siccitate imbricata apicem versus aperta, madefacta squarrosa patentia, ovata, longius acuminata, dense areolata; cellulis apicalibus minutis ovato-angulatis haud vel vix prominulis; alaribus transverse elongatis quadrangularibus seriatim distincte dispositis; costa sub medio abrupte dissoluta quandoque basi furcata brevi. Perichætialia late ovata, sub apice rotundata, breve acuminata, costa valida vel in vel sub apice evanida.

Inflorescentia generis.

Capsula ovata, brevissime pedicellata, immersa; peristomii duplicis dentibus lineali-lanceolatis; ciliis filiformibus albidis; annulo composito; operculo conico-obtusiusculo; calyptra conica integerrima.

HAB. Florida (*J. D. Smith*).

The dark color of the plants, the long flexuous slender filiform stems, rarely simple, generally forking above the middle or divided in tufts of flabellate capillary short branches, the form and disposition of the longer leaves open or recurved at the top, the areolation, the straight conical operculum, and the entire calyptra are the essential characters which separate this species from *Cryphæa glomerata*, to which it is closely related.

HYPNUM WATSONI. Caulis erectus sat regulariter pinnato-ramulosus, ramulis approximatis.

Folia hamulato-secunda, parvula, breviuscula, e basi lata ovato-oblonga concava lanceolata et recurva plus minus longe anguste acuminata et subulata, margine integro præprimis versus apicem reflexo,

basi obsolete bicostata; reticulum pertenue areolis perangustatis breviter vermiculatis in toto folio subæqualibus.

Flores dioici; perichætium in ramulo perichætiali perbrevi haud radicante longum vaginans; folia perichætialia interna elongato-lanceolata, subulato-acuminata, apice denticulata, tenuissima, pallida, longitudinaliter plicata, plicis angustis, reticulo laxiore tenuissimo.

Capsula leniter cernua, elongato-subcylindrica, sicca arcuata sub ore leniter constricta; operculum oblique rostratum, rostro mutico.

Color totius plantæ lutescens et fuscescens. Habitus et modus crescendi *H. Bambergeri.*

Hypnum imponens, James in Bot. King Exp. 410.

HAB. On rocks, Bear River Cañon, Uinta Mountains, Utah (*Watson*, no. 1474).

This species is comparable at first sight to some of the varieties of *H. uncinatum*, but is different from this and related congeners in its inflorescence, form, areolation of leaves, &c.

HYPNUM ALASKANUM. Differt ab *H. Schreberi* proximo gracilitate plantæ densius et regulariter pinnatæ; foliis caulinis minoribus solidioribus, apice minus late rotundatis, margine remote serratis; reticulo validiore, areolis totius folii vermicularibus et præprimis superioribus angustioribus et brevioribus; præsentia paraphylliis multifidis.

HAB. On the ground in Alaska (*W. H. Dall*).

Distinguished from *H. Schreberi* by its densely pinnated form extending the whole length of the stem, also by its broader and slightly serrated leaves and dark color.

The following descriptions, with remarks on some new American species, have been communicated by Professor Schimper: —

EPHEMERUM SPINULOSUM, Schimp. Differt a *E. crassinervio*, foliis angustioribus mollissimis versus basin ecostatis, parte superiore costa instructis lata laxe texta in aristam longam mollem circa circum hyalino-spinulosam excurrente; capsulæ membrana laxius texta.

HAB. Moist clayey grounds and on river-banks.

Schwaegrichen's *Phascum crassinervium* is a Pennsylvania moss, and the same as *Ephemerum crassinervium* of Sullivant's Icones, but not identical with *E. crassinervium*, Bryol. Eur., which is *Phascum stenophyllum*, Voit (*E. stenophyllum*, Schimper, Synopsis, second edition). [There is great difficulty in separating these forms, which are often found together, and so closely allied by intermediate variation that it is scarcely possible to decide which of these species is represented by the specimens. Considering merely the variations in

the leaves, a number of species could be described from single specimens taken separately for examination. L. & J.]

Systegium erythrostegium, Br. & Sch. Caulescens, parce ramosum. Folia humida patula, sicca cirrhoso-tortilia, e basi ovali anguste lanceolata, concava, margine inflexa, solide costata; perichætialia longiora, angustius acuminata.

Flores monoici; masculus in innovationibus terminalis, tandem pseudo-lateralis, gemmiformis, pentaphyllus, antheridiis brevipedicellatis, paraphysibus circiter 10 brevioribus.

Capsula immersa, in planta sicca emersa, ovalis; operculo persistente conico rufulo; pedicello capsulam æquante pallido recto exsiccatione nonnunquam curvulo.

Phascum crispum, var. *rostellatum*, Hooker & Wilson in Drummond's Musci Americani (Southern States), no. 10.

Hab. Near New Orleans.

Orthotrichum brachytrichum, Schimp. Humile cæspitulosum, cæspituli pallescente-virides, ætate fusco-luteo variegati. Planta vix semiuncialis, ramosa, tenella.

Folia ex ovato et oblongo lanceolata, superiora elongato-linealia, apiculata, lutescente-viridia, acute carinata, margine subrevoluto-reflexa, minutissime papillosa, areolis partis superioris parvulis rotundatis, basilaribus rectangulis hyalinis; costa angusta sub apice evanida.

Flores monoici; masculi in ramulis propriis ut in *Orth. pallente*, in eodem ramulo complures gemmiformes; antheridia 8–10 eparaphysata vel paraphysibus singulis.

Fructus: calyptra pallide straminea apice pilis paucis brevibus instructa. Capsula in pedicello vaginulam cylindricam nudam tubo longo auctam æquante supra folia perichætialia erecta, paulum emergens, unacum collo longiusculo subcylindrico-oblonga, lutescens, striis luteis siccitate costas efformantibus; operculum sulphureum convexum apiculatum; peristomii dentes 8, parvi, bigeminati, integri, areolis magnis punctulatis; cilia 8, dentibus æquilonga, lævia; membrana capsularis tenuis, laxe texta, reti subrectangulo tenui in striis paulum crassiore, stomatibus perpaucis magnis emersis.

O. obtusifolium, Drummond's Musci Americani (Northern States), no. 157.

Hab. On trees, from Upper Canada to the Rocky Mountains.

Plagiothecium pseudo-Silesiacum, Schimp. Monoicum. Rami subcomplanato-foliosi, foliis anticis adpressis lateralibus et posticis patentibus confertis ovatis tenui-acuminatis serratis ecostatis angus-

tissime rhomboideo-areolatis, perichætialibus imbricatis ovato-lanceolatis. Capsula in pedicello recto subunciali obliqua vel inclinata, ovali-oblonga, leptoderma, pallide badia, siccitate longitudinaliter sulcata; annulo duplici revolubili; operculo late conico brevi.

Hypnum Silesiacum, Hooker & Wilson in Drummond's Musci Americani (Southern States), no. 111.

HAB. Near St. Louis.

INVESTIGATIONS ON LIGHT AND HEAT, made and published wholly or in part with appropriation from the RUMFORD FUND.

XI.

DISTRIBUTION OF HEAT IN THE SPECTRA OF VARIOUS SOURCES OF RADIATION.

BY WM. W. JACQUES, PH.D.,

Fellow of the Johns Hopkins University.

Presented April 9, 1879.

THE following research has had for its object a study of the distribution of heat in the spectra of a variety of substances, each heated to various temperatures.

Experiments upon the distribution of heat in the sun's spectrum have already been made by a large number of experimenters, and a few have measured the heat from some terrestrial sources. The former class have failed to give us much scientific information, both because we know so little about our source of radiation, and because we are so little able to estimate the absorbing effect of our atmosphere upon the rays that are given out. The latter class have been too limited, and they are too little comparable with each other. In all of them there may be detected very considerable errors. In fact, the experiments that have thus far been made have hardly more than served to guide us in selecting the best methods and apparatus for further research, and to point out the more important sources of error.

In this research the author has made use of such results as the various experimenters upon the distribution of heat in the spectrum, from the time of Sir W. Herschel down to the present day, have obtained; and, profiting by them, has attempted to advance the method one step further, and to determine some relations between the quantitative structure of various substances and the distribution of energy in their spectra, as well as the effects of varying temperature, of liquefaction, and of chemical change of a source of radiation, upon the kind of rays it gives out.

The experiments have included a measurement of the distribution of heat in the spectrum of a platinum wire, heated to various measured temperatures between a low red and a full white heat, which resulted in the discovery that platinum gives a spectrum in which the relative distribution of energy is nearly the same for all temperatures between these limits.

That is, if we represent the intensities of heat at different parts of the spectrum by ordinates, the curve joining these will have nearly the same geometrical form, and the same position of the maximum, for all temperatures of the wire between these limits. The curve of distribution was then determined at a low red heat, at a bright red, and at a white heat for the black oxide of copper (CuO), the black oxide of iron (Fe_3O_4), the red oxide of iron (Fe_2O_3), the green oxide of chromium (Cr_2O_3), and the white oxide of aluminium (Al_2O_3).

It was found that for each substance the geometrical form of the curve was nearly independent of the temperature, but that it varied somewhat with the different substances.

A relation between the molecular weights of these substances and the forms of the curves, and also a relation between the colors of the bodies at the ordinary temperatures and the radiations emitted when heated, appeared in a study of their curves. The effect of the passage from the solid to the liquid state was studied in the case of CuO, and it was found that the geometrical form of the curve remained the same.

The present paper contains a review of the more important experiments that have been made upon this subject, and to these there is added an account of the author's own experiments.

HISTORICAL.

Previous to the time of Sir Wm. Herschel there had been no really scientific study of the distribution of heat in the spectrum.

As the results of three very limited and inaccurate series of experiments, by Landriani,* Rochon,† and Senebier,‡ it was supposed that the sun's rays of light were accompanied by rays of heat, which were in general stronger for rays of low than for those of high refrangibility, but which reached their maximum somewhere in the yellow or orange rays.

---

* Ann. der Physik, x.

† Recueil de Mém. sur la Méc. et Physique, 1783.

‡ Mem. Physico-chemiques, ii. 74.

In 1800 Sir Wm. Herschel published in the Philosophical Transactions a series of experiments on this subject, which were, without doubt, as accurate as the means at his command would allow, and which later experiments have amply confirmed.

He allowed the spectrum formed by the passage of the sun's rays through a glass prism to fall upon a screen, in which there was a slit, which could be moved to different parts of the spectrum. Behind this slit he placed a very sensitive thermometer, and, moving the slit through the spectrum, found that, after successive exposures of ten minutes each, it rose in the violet 1°.1; in the green, 1°.8; in the red, 3°.8. Moving the slit still farther and beyond the limits of the luminous spectrum, he found that on the very border of luminosity the thermometer stood at 3°.6, and even at a distance of five centimeters from this point the reading was 1°.7. In the ultra-violet there was no effect.

The field having thus been opened, various experimenters took up the subject, in order to find the form of the curve of distribution, and the position of maximum heating effect.

Leslie,* in repeating Herschel's experiments with what he claimed to be a delicate differential thermometer, found, as the experimenters previous to Herschel had, that the maximum was within the luminous spectrum, and, in a somewhat severe criticism of Herschel's work, attributed his results to the heating of the inclined plane on which the thermometers were placed.

Mickle,† in experimenting on the subject, found that the prism itself became somewhat heated, and concluded that Herschel's apparently anomalous results were due to radiations from the prism.

Englefield‡ found, as Herschel had done, that the maximum was in the ultra-red.

An accurate series of experiments carried out by Wünsch,§ and a perhaps still more praiseworthy series, which tended only to confirm the first, made by Seebeck,‖ showed that the form of the curve and the position of the maximum was largely dependent upon the material of the prism used, and that Herschel's results were, for the kind of glass used, entirely correct.

In 1833 Melloni ¶ published in the *Ann. de Chimie et de Physique* the results of a very accurate and extended series of experiments on

* Nich. Journ., iv.
† Phil. Mag., lxv.
‡ Journ. Roy. Inst., 1802.
§ Gehler's Journ., vi.
‖ Abhandl. d. Berl. Akad., 1819.
¶ Ann. de Chimie, liii.

the radiation of heat, in which his measurements were made with the thermopile instead of mercury thermometers.

These researches included a study, made with this instrument, of the distribution of heat in the spectrum. He found, as Wünsch and Seebeck had done, that the distribution of heat was dependent upon the material of the prism used, and that the reason why different substances gave different spectra was because each possessed an absorptive power for certain of the heat rays. The selective absorption of some substances gave rise to sinuosities in the curve of distribution.

There was one substance, however, that he found to be transparent for all rays, both of light and heat. This was rock-salt. Fluor-spar he found to be the nearest to approach it in diathermacy. Resuming the study of the spectrum with prisms of rock-salt and the thermopile, he found the maximum to be at a distance beyond the red equal to the distance of the yellow from the same.

In the Philosophical Transactions for 1840, Sir John Herschel published the results of a series of measurements of the distribution of heat in the spectrum, made by exposing to its rays a thin blackened paper, which had been covered with some easily evaporated liquid. The points of greatest intensity of heat showed themselves by the greatest evaporation of the liquid. His results were, in general, similar to those previously obtained, but, in addition, he claimed to have discovered lines of discontinuity, similar to the Fraunhofer lines of the luminous spectrum.

Melloni, in the *Comptes Rendus* * for the same year, criticises the results obtained by Herschel, and says that they cannot be regarded as an accurate measurement of the distribution of heat, because the blackened paper would not absorb all the rays in the same proportion, and because its conductibility would extend the evaporation at points of great to those of low intensity. The lines of discontinuity he claims to have discovered himself, and to have explained by the selective absorption of the prism.

In 1858 a research upon the distribution of heat in the sun's spectrum was made by J. Müller.† He used prisms of rock-salt and of glass for obtaining the spectra, and a carefully constructed thermopile and galvanometer for estimating the temperatures. His experiments included a study of the effects of interposing various colored solutions in the paths of the rays, and, later, studies of the effects of using different prisms. With regard to the position of the

* T. xi.

† Pogg. Ann., cv.

maximum, his conclusions were substantially the same as those of Melloni.

In addition, he made some estimates of the wave-lengths of the dark parts of the spectrum by means of an empirical formula, derived from measurements in the luminous spectrum. As a result of these calculations, he found the wave-length of the limit of the dark spectrum to be 0.00183$^{mm.}$. He admits, however, that this value is very inexact, and we shall see further on that it can hardly be considered an approximation, both because the method is so crude, and because the limit of the spectrum cannot be fixed.

Dissatisfied with his results, he experimented upon the spectrum from a diffraction grating, in which the elongation of the spectrum is proportional to the wave-length.

Similar experiments had already been made by Draper,* who stated as the result of his observations that the distribution of heat corresponded to the distribution of light and reached its maximum in the yellow.

Draper's experiments were made with somewhat crude and not very delicate apparatus, and Müller, in repeating them with a much more sensitive thermopile, found, as Draper had done, that the maximum of the diffraction spectrum fell in the yellow, but he did not find the intensities of heat proportional to the light.

The curve of distribution which he obtained rose very steeply from the violet to the yellow, and then fell gradually and became insensible at a point distant from the red equal to three and one half times the length of the luminous spectrum.

The reason of the non-coincidence of intensity of the luminous and thermal spectra had been sought by Melloni† (who thought it was due to a coloration of the crystalline lens), and by Brücke,‡ Cima, Tyndall, and Jansen.

But the most complete research seems to have been carried out by Franz,§ who published an article upon the diathermacy of the media of the eye in 1862. In these experiments, he interposed the various media of the eye, placed between plates of rock-salt, in the path of the rays, which were afterward dispersed by a rock-salt prism, and found that the humors of the eye all absorb the ultra-red rays very largely, and the luminous rays to a much smaller extent.

He also showed, by measuring the distribution of heat in the sun's

* Phil. Mag., 1857, xiii. 153.

† Pogg. Ann., lvi.

‡ Pogg. Ann., lxv. and lxix.

§ Pogg. Ann., cxv.

spectrum on days of different degrees of clearness, and at different seasons of the year, that the watery vapor absorbed the non-luminous rays so largely, and in so different a proportion to the absorption of the luminous rays, that on two days in August, only nine days apart, the non-luminous spectrum extended, in one case, only as far beyond the red as the green was on the other side, and, in the other, a distance equal to the luminous spectrum. He concluded, from his observations, that it is not possible to make quantitative studies, if the sun be used as a source of light, nor if the eye be used in measurements.

Knoblauch* published in 1863 the results of a series of experiments upon the transmission of radiant heat through rock-salt, in which he studied the effects upon the distribution of heat in the spectrum. He concluded from his experiments, that prisms of chemically pure rock-salt allowed rays of heat of all kinds to pass through in equal proportions; that the maximum of the solar spectrum found by such a prism fell outside the red, and that the distribution of heat for the luminous part of the spectrum is the same for prisms of rock-salt and of glass.

Cloudy rock-salt, however, he found, interrupted rays from the sun more than from an Argand burner, and rays from this burner more than from a source heated to 100° C.; and also that chemically or mechanically impure rock-salt diffused the light and exercised a selective absorption. He obtained, also, many other results, which are not, however, of special interest here.

The next experimenter in this field was Desaines,† who used, as a source of heat, pieces of lime and platinum heated to incandescence in a lamp. The prism used was of rock-salt. He found that the maximum was beyond the red rays, and that water absorbed the ultra-red. Comparing the spectrum from platinum with that from the sun, he found that, while the maximum for platinum was 1.°15 from the line of no dispersion, for the sun it was 0.°46 at 8 A.M., and 0.°51 at noon.

Lamansky‡ explored the sun's spectrum with a very narrow thermopile, and found in the ultra-red spectrum places of low heat, which he says are similar to the Fraunhofer lines of the luminous spectrum. But these, as we have seen, had already been noticed by Herschel, and were attributed by Melloni to the absorption of the prism.

Lamansky, however, finds that, so long as the sun is used as a source of heat, these lines appear the same for a prism of bisulphide of car-

* Pogg. Ann., cxx.
† Comptes Rendus, lxx.
‡ Pogg. Ann., cxlvi.

bon as for one of rock-salt, and that when the calcium light was substituted for the sun they entirely disappeared. These lines, he found, were in groups, each of which was quite broad. The index of refraction of the farthest group he estimated at 1.5274.

There are two other series of experiments, brief notices of which seem to be necessary for the completion of the history of the subject. That of Tyndall* on the distribution of heat in the spectrum of the electric light; and that of Draper,† in which he compares the heat of equivalent parts of the spectrum.

The experiments of Professor Tyndall were made with exceptionally fine apparatus, and undoubtedly represent the distribution from the electric light with considerable accuracy. The curve he obtains is somewhat symmetrical about its point of maximum, and this maximum is found at a distance beyond the red about equal to the distance on the other side of the green. The total length of the invisible spectrum measured was about *twice* that of the visible. The ordinates near this point of maximum he found to be very much greater, compared with those of the luminous spectrum, than those found by other experimenters. He also experimented upon the effect of introducing water and various other media in the path of the rays, with results essentially similar to those we have already seen.

Professor Draper, in his paper, calls attention to the fact, that in the prismatic spectrum the length of any part is not, as in the diffraction spectrum, proportional to the differences in wave-length of its extremes, but is more and more condensed as we go from the violet to the red.

He supposes this to be the reason of the apparent increase of thermal effect, and shows, by an extended series of experiments, that the amount of heat between the A line, for which $\lambda = 7604$, and the point for which $\lambda = 5768$, when converged by a concave mirror upon a thermopile, had nearly the same heating effect as the portion between $\lambda = 5768$ and the H_2 line, for which $\lambda = 3933$; $\lambda = 5768$ being the mean of the other two wave-lengths, and called by him the optical centre.

From this, he says, "it necessarily follows that in the spectrum any two equivalent series of undulations will have the same heating power, no matter what their actual wave-length may be." A conclusion, however, which we shall see is by no means correct.

---

* Phil. Trans., 1866. † Am. Jour. Sci., 1872.

In the above historical sketch I have tried to represent, as fairly as possible, what has been done in the way of measuring the distribution of heat in the spectrum. Some of the results are undoubtedly quite wrong, and nearly all of them contain very considerable errors; but the experiment is a delicate one, and the results are peculiarly liable to modification from disturbing causes. The results often vary very widely, even when obtained by eminent observers and with excellent apparatus; the reason being that the unknown conditions of the problem have been so different.

Though so large a number of researches have been undertaken, they have all been entirely qualitative. The source of radiation, the dispersing medium, and the means of measuring the heat in the spectrum, have been varied, and the qualitative effects noticed.

The following research has been undertaken with a view to determining the quantitative relations that may exist between the nature and the temperature of the source of radiation, on the one hand, and the geometrical form of the curve of distribution, on the other. A long and laborious series of preliminary experiments was made, in addition to a study of those of other experimenters, in order to determine the nature and magnitude of the disturbing causes. A few of these may, perhaps, be best referred to here, but the larger number will appear in an examination of the apparatus, in which the preventive means also appear.

The first difficulty is, of course, the absorption exercised by the rock-salt lens and prism. Although chemically pure and perfectly cloudless rock-salt has so little selective absorption as to make it an unimportant factor in these researches, the slightest deposition of moisture, or the slightest cloudiness of the material, will exercise a very decided influence. A deposition of moisture, not noticeable to the eye, may form a slight coating of brine that will quite materially alter the form of the curve.

This was a serious cause of error in my preliminary experiments, and undoubtedly has considerably interfered with other experimenters' results. To prevent this, cloudless rock-salt was chosen in the first place, and carefully polished with oxide of tin and alcohol before using. It was afterwards always kept in a perfectly dry atmosphere, secured by means described later.

The selective absorption of the thermopile was guarded against by covering the face with carefully deposited camphor-black, — the selective absorption of which must be too small to enter as a factor here, —

and using the same coating through all the experiments; so that such error as may have been introduced only entered in its differences.

The superposition upon the spectrum of the reflection from the back of the prism causes a considerable error. This was cut off by a screen of card-board.

There is another source of error, pointed out to me by Dr. Hastings, which fortunately was sufficiently small to be neglected here, but which may prove to be of considerable magnitude in differently arranged or in more delicate experiments.

If the prism be, as is usually the case, and as was the case in these experiments, one having equal angles, the part of the ray interiorly reflected from the second surface upon which the light strikes will be reflected again from the back and from the first side of the prism, and when it comes out of the prism will form an undispersed image superimposed upon the spectrum.

If the two angles at the back of the prism be denoted by β and γ, we have as follows:

Deviation after first interior reflection $= \theta = \pi - 2\,i$
" " second " " $= \theta_{\prime} = \pi - 2\,i_{\prime}$
" " third " " $= \theta_{\prime\prime} = \pi - 2\,i_{\prime\prime}$

Total deviation $= \Delta = \Sigma\,\theta = 3\,\pi - 2\,\Sigma\,i$

Suppose $i = \frac{\pi}{2} - \beta + \theta,$

then $i_{\prime} = 2\,\beta - \frac{\pi}{2} - \theta,$

and $i_{\prime\prime} = \gamma - 2\,\beta + \frac{\pi}{2} + \theta$

$$\Sigma\,i = \frac{\pi}{2} - \beta + \gamma + \theta$$

$$\Delta = 2\,\pi - 2\,(\beta - \gamma) - 2\,\theta.$$

Suppose $\beta = \gamma$, and $\theta = 0$, then $\Delta = 2\,\pi$, that is, an image of the slit is formed on the screen at a point where the ray has minimum deviation.

For a ray of different refrangibility

$$i = \frac{\pi}{2} - \left\{\beta = \gamma\right\} \pm \theta,$$

and

$$\Delta = 2\,\pi \mp 2\,\theta.$$

Hence an image formed by two refractions and three internal reflections is undispersed.

If the index of refraction $= n = 1.54$, from Fresnel's formulæ, we have the intensity of the image about $\frac{1}{500}$ of the whole prismatic image.

If now the area of the curve be greatly larger than the width of the thermopile slit $\times$ maximum ordinate, this superimposed image may be a considerable cause of error.

The measured spectrum extended over about $140^{mm.}$, but the ordinates were comparatively very small, excepting over about $50^{mm.}$; so that the curve may be considered very nearly equivalent to a triangle, with altitude h (maximum ordinate), base $50^{mm.}$, and the area $25\,h^{mm.}$

The width of the slit was about $5^{mm.}$, and we have $5\,h^{mm.}$ to compare with $25\,h^{mm.}$, or a quotient of $\frac{1}{5}$ which is contained in the $\frac{1}{500}$ $\frac{1}{100}$ times, i. e. there would be an error of about 1%.

This, however, is within the limits of probable error, and as the image always fell near the maximum ordinate, it was never noticed in the experiments. Besides these causes of error there was, at first, trouble on account of diffuse radiation from the source, heating, and consequent radiation from the prism, radiation from surrounding objects, change of temperature of pile, variations of temperature of the source due to air currents, heating of bodies near the source, moisture of the air, and many disturbances of the galvanometer used with the pile, due to change of sensitiveness of the needles and to changes in the earth's magnetism. But these and other errors have been avoided in the apparatus to be described.

The source of radiation was a strip of heavy platinum foil, about $15^{mm.}$ long and $1^{mm.}$ wide, heated by a current of electricity. The experiments on the radiation from platinum were made from this wire direct, and those from the various other substances by coating the foil with the substances to be experimented upon; the heat generated by the current in the foil being sufficient to raise the substance to incandescence. The radiations from this wire were focused by means of a rock-salt lens, and dispersed by a rock-salt prism. A delicate thermopile was moved through the spectrum thus formed.

On the long table in the centre of the plate was a wooden box about seven feet long, and of the shape shown in the figure. This was intended to shield the experiment from outside radiations, and, besides being closed, was wrapped with woollen cloths during an experiment.

At S was placed the platinum wire, which was mounted between two brass rods, tt' (Fig. 2). These rods were themselves mounted

in a vulcanite frame, and were connected, one with the battery direct and the other through the tangent galvanometer G, and the variable resistance R; c was merely a commutator for reversing the current through the galvanometer; w' w' (Fig. 1) are two exceedingly fine platinum wires welded to the main wire, about 8$^{mm.}$ apart, and connected with a second galvanometer, G'. The object of these was to shunt off a small portion of the current, which, being compared with the main current, gave a method of determining the temperature of the large wire: this method will be further described.

The vulcanite frame was enclosed in a box of polished tin, shaped as shown in the figure. This peculiar shape was intended to reflect such rays as did not fall directly upon the lens to one side, and finally to the back, where they were absorbed by the V shaped partition, behind which was a compartment filled with water.

The current for heating the wire came by means of the wires w, from a battery of thirty-two Bunsen cells, placed in the room below. It was measured by the galvanometer, G, placed on a stone pier, and its strength regulated by a mercury resistance, R.

The part of the current shunted off by the wires w' w' was measured by a delicate galvanometer, G', also placed on a stone pier. In this circuit there was a resistance of 1,000 ohms t, and a commutator c' for reversing the current through the galvanometer.

The rays that were given out by s passed through an opening, which could be closed, if desired, by the door of double tin, a, fell upon the rock-salt lens L and the rock-salt prism P, and produced a spectrum at $v\ b\ r$ about 15$^{cm.}$ long. The lens and prism were both of perfectly transparent cloudless rock-salt. The lens was mounted in a double tube of brass, for focusing, the distance $S\ L$ being about 14 inches.

The prism was set on a plane surface, so as to be easily rotated or moved in any direction. It was set at its angle of minimum deviation by means of the reflection from the back, which, moving through twice the angle that the prism was moved, and over an arc whose radius was the distance from the prism to the pile, some four feet, furnished an excellent method of setting at the angle of minimum deviation for any part of the spectrum. After setting, this reflection was cut off by means of a little screen placed at the corner of the prism.

The thermopile T was covered with camphor lamp-black, and enveloped, with the exception of the slit, by a double casing of tin. The back part of this was filled with water to absorb the extra rays, and to keep that face of the pile at a constant temperature. This screen,

with the enveloped pile, was fixed to a slide, $b\ d'$, so that it could be moved through the spectrum; the position of the pile being read off on a scale at d'. The tin case and pile also had a vertical motion, so that it could be raised and replaced by a simple slit, which was directly under the face of the pile. This slit was used in reducing the spectrum to that of the sun, by a method to be presently described.

Of course the heat radiated by the wire is very feeble, particularly after being dispersed by the prism, and we know that even the spectrum of the sun is not easy to measure. The ordinary short-coil Thomson galvanometer, when used with the pile, gave scarcely any deflection, even at the point of maximum heating effect of the spectrum, and in the luminous spectrum it gave no deflection at all.

Accordingly the Thomson galvanometer was modified as follows. The brass rod and magnet were removed, a hole made in the top, and a glass tube, about $25^{cm.}$ long, placed over this. Inside this was suspended an exceedingly fine silk thread, to the bottom of which was suspended the needle. It was necessary to form a suspension of this length, in order to eliminate the viscosity, which, even in a needle as delicate as the one used, was quite noticeable. The needle was made of eight small bars, about $8^{mm.}$ long, $1^{mm.}$ wide, and $1^{mm.}$ thick, placed four in the centre of the coil, and the other four, with poles reversed, below the coils. They were as nearly as possible in the same plane, and the system was found, when adjusted, to be so nearly astatic as to swing in fifteen seconds. The slight adjustment that was necessary was made by means of a small magnet, arranged so as to move in any plane, and placed at the side of the galvanometer at m.

This galvanometer was placed on a stone shelf at G'', and its deflections read off by means of a scale and a spot of light at d. C'' was a commutator for reversing the current through the galvanometer. This galvanometer was, of course, exceedingly delicate; the passing of a finger by the pile was enough to throw the spot of light off the scale. It was exceedingly sensitive to changes in the earth's magnetism, so much so that on many days no observations could be taken at all. This, however, was avoided in general by reading on both sides of the 0 point of the scale, and by making the observations late in the evening, when the magnetic disturbances were at a minimum. Its sensitiveness, however, enabled the observer to detect the radiations of the violet part of the spectrum when the wire was heated to a white heat.

One great advantage of using so slight heating effects of the pile, and determining these by a low-resistance galvanometer, is that we

are much more certain that the galvanometer deflections are proportional to the heating effects.

Of course special precautions had to be taken to keep the lens and prism entirely free from moisture, a thin coating of which, such as would be deposited from the open air, would entirely vitiate the results. This was done by making the box one large desiccator, the bottom being covered completely with lead pans filled with pumice-stone and sulphuric acid, pans of these being clustered everywhere about the lens and prism. The lens and prism have now remained several months in the box with hardly an appreciable change.

Determination of Temperature.

I have described briefly the method of determining the temperature of the source of heat, but it still remains to describe the process more in detail, and to give the theory of the method. It was my intention, in beginning the experiments, to determine the temperature by measuring the variation of resistance of a platinum wire; but this particular arrangement of the apparatus was suggested to me by Professor Rowland.

We have seen that the current from the battery comes through the wire, which was rather a strip of platinum foil, then through the tangent galvanometer G, where it may be accurately measured, and then through the resistance R, where its strength is regulated. By setting up the cells, so that the internal resistance of the battery was very small, a constant current was easily obtained.

The two fine shunting-wires w' w' took off an exceedingly small portion of this current, which was measured by the sensitive sine galvanometer G'. The theory of the method is as follows.

Let $C =$ whole current from battery; C', the current through the platinum wire; C'', the current through the shunt. Let E, E', E'' be the corresponding electro-motive forces, and R, R', R'' the corresponding resistances.

Then $\quad C' = C - C'' \qquad\qquad E' = E'' = C'' R''$

and $$R' = \frac{E'}{C'} = \frac{C'' R''}{C - C''} = \frac{C'' R''}{C}$$

(since C'' is very small).

In general, for any value of the resistance of the platinum-wire,

$$R = \frac{k\,h \sin U R''}{K H \tan V} = R\,(1 + a\,t + b\,t^2 + \&c.)$$

Let $R_{\prime}$ be the resistance at some known temperature $t_{\prime}$, and $V_{\prime}$ and $U_{\prime}$ the known corresponding deflections of the galvanometers, then

$$R_{\prime} = \frac{k\,h \sin U_{\prime}\, R''}{K\,H \tan V_{\prime}} = R_0\,(1 + a\,t_{\prime} + b\,t_{\prime}^2 + \&c.)$$

For any resistance $R_{\prime\prime}$, we write in the same way:

$$R_{\prime\prime} = \frac{k\,h \sin U_{\prime\prime}\, R''}{K\,H \tan V_{\prime\prime}} = R_0\,(1 + a\,t_{\prime\prime} + b\,t_{\prime\prime}^2 + \&c.)$$

From these two equations, by proportion,

$$R_0(1+at_{\prime\prime}+bt_{\prime\prime}^2+\&c.)=\frac{k\,h \sin U_{\prime\prime}\, R''}{K\,H \tan V_{\prime\prime}}\,\frac{K\,H \tan V_{\prime}}{kh \sin U_{\prime}\, R''}\,R_0(1+at_{\prime}+bt_{\prime}^2+\&c.)$$

or simply,

$$1 + at_{\prime\prime} + bt_{\prime\prime}^2 + \&c. = \frac{\sin U_{\prime\prime} \tan V_{\prime}}{\tan V_{\prime\prime} \sin U_{\prime}}\,(1 + a\,t_{\prime} + b\,t_{\prime}^2 + \&c.)$$

If now we know the values of $t_{\prime}$ and $\frac{\tan V_{\prime}}{\sin U_{\prime}}$ for any one case, and the coefficients a and b, we may, by simply reading $U_{\prime\prime}$ and $V_{\prime\prime}$ for any other current, determine the temperature from this equation.

As, for example, to determine $t_{\prime\prime}$ we have merely to substitute the readings of the galvanometers $U_{\prime\prime}$ and $V_{\prime\prime}$ and solve relatively to $t_{\prime\prime}$.

The coefficients a and b have already been determined by Benoist,* viz.,

$$a = .002445 \qquad b = .000000572$$

To determine $U_{\prime}$ and $V_{\prime}$ for some temperature $t_{\prime}$, the wire was submerged in water at that temperature. This, of course, had to be repeated every time the wire was changed for a new one.

As may be seen upon examination, the theory of the method has nothing objectionable in it, and its practical accuracy depends upon the determination of the coefficients a and b. These were carefully determined by Benoist up to 860° C. For temperatures very much beyond this, as between 1,000 and 2,000 degrees, there is a liability to some error. But it is easily seen that the method is vastly superior to that of determining the temperature by the method of expansion.

Reduction to Sun's Spectrum and Determination of Wave-Lengths.

The image of the spectrum, as formed in the plane of the face of the pile, could be measured only in terms of divisions of the arbitrary scale attached to the slide on which the pile was placed. In order to determine the wave-lengths of the different parts of the spectrum for

* Phil. Mag., April, 1876.

which the thermal intensities were measured, it was compared with the sun's spectrum by the following method. The pile was made to slide up vertically so as to be replaced by the slit beneath it. This slit could then be moved to different parts of the spectrum, and its position read off on the same arbitrary scale as the thermopile. In fact, the readings for the two would be identical. Behind this slit was placed the slit of a single prism spectroscope, having a third tube and a photographed scale. As the pile was moved to different parts of the luminous spectrum an image of the slit beneath it was formed on the scale of the small spectroscope and its position could be read off in terms of the arbitrary scale.

A table was then formed containing in one column the readings of the thermopile scale, and in the second the corresponding readings of the spectroscope scale. Then the spectroscope was turned toward the sun and the positions of the principal Fraunhofer lines read off in terms of its scale. These readings formed a third column, and it was easy, by proper interpolation, to determine the position of these Fraunhofer lines in terms of the thermopile scale.

It now remained to determine the wave-lengths of these lines. This has already been done with great accuracy by Professor Powell,* and accordingly his values for these lines were made use of. The wave-lengths of the non-luminous portion were determined by means of empirical equations based on observations made in the luminous portion of the spectrum. Any considerable extension was, of course, accompanied with great error.

Some experiments with a diffraction grating are contemplated, and, if successful, will greatly help in determining the wave-lengths of the various parts of the curves here given. It must be remembered, however, that these experiments are principally of value in their relation to each other, and that the absolute determination of wave-length is therefore of only secondary importance.

Experiments with Platinum.

These experiments consisted of ten final and many other preliminary series of measurements of the distribution of heat in the spectrum of a platinum wire when heated to various measured temperatures between a low red and the point of fusion.

The method of experimenting was as follows. The vulcanite frame, containing the wire with its shunt, was first submerged in water of a known temperature, a faint current sent through it, and readings

---

* Pogg. Ann., lxix.

taken of the tangent and the sine galvanometers; this last being very sensitive, and the instrument used for measuring the small shunted current. This process was necessary every time a new wire was put in the frame, in order to obtain a constant that entered into the formula for determining the temperature. It was found necessary to change the radiating wire a great many times during the experiment, because of fusion by too strong a current.

The above process being completed, the vulcanite frame was set in position in the box, and a strong current sent through the wire so as to make a brilliant luminous spectrum. The pile was then raised so as to be replaced by the slit, the small spectroscope placed behind this, and an exploration of the luminous spectrum made.

The pile was then lowered into position, the box carefully closed and covered with cloths, and left for several hours with the current cut off, so that everything in the interior might come to the same temperature. An even temperature being secured, sufficient current was sent through the wire to bring it to a low red heat, and the thermopile was moved step by step through the entire spectrum, and then back again; readings of the galvanometer being taken on both sides of the 0 at each step. The order of exploring the spectrum was sometimes reversed, sometimes the observations were begun at the middle and alternated, first to the right and then to the left, until the extremes were reached, and sometimes the order was from the extremes towards the middle. The method was thus varied in order to eliminate any possible error. The exciting current was kept constant during these measurements by means of the mercury resistance, and readings taken of both the tangent and sine galvanometers on both sides of the 0.

This series being completed, the temperature was varied and the experiment repeated; and so on for any number of temperatures, each series occupying from two to four hours' time. The results of the ten series are given in Table I., and are graphically represented by the curves of Plate II. These curves are each the mean of several observations, and are sometimes filled out in part from different series, all being reduced, of course, to the same ordinates and abscissas. Each curve has been constructed by plotting all the observations upon which it is founded, and drawing a mean curve through them. The number of series of measurements that entered into these curves was fifty-two.

The table shows the co-ordinates of the points of these mean curves. With each is given the temperature, and probable error of determination of a point near the B line. The points near the maximum were, of course, determined with far greater accuracy.

The experiment is one containing so many errors that it could not be expected that the experimental curves would be very accurate; but the large number of experiments made, on the other hand, give the mean curve probably with considerable accuracy.

An inspection of Plate II. shows us at once the important fact, that, though the temperature varies very considerably, the geometrical form remains very nearly, if not exactly, the same.

Of course it is quite possible that further and more delicate experiments may show slight variations in the form of this curve.

In fact, it is well known from the experiments of a large number of experimenters, and, indeed, from the change of color of the light as the temperature of a source of radiation is raised, that the geometrical form of the curve cannot be *entirely* independent of the temperature.

But such phenomena might easily be caused by variations too delicate to be detected by the thermopile.

TABLE I.

	OCT. 8.	NOV. 7.	SEPT. 27.	OCT. 9.	OCT. 8.	NOV. 7.	NOV. 6.	SEPT. 28.	OCT. 8.	NOV. 7.
	T = Faint red. p. e. = .07	T = 774° p. e. = .06	T = 870° p. e. = .09	T = 850° p. e. = .07	T = 850° p. e. = .04	T = 854° p. e. = .05	T = 795° p. e. = .08	T = 850° p. e. = .07	T = 1025° p. e. = .04	T = 1000° p. e. = .04
2		.06	.14	.18	.24	.30	.34	.36	.41	.45
2½										
3		.07	.17	.22	.27	.34	.38	.40	.47	.51
4	.02	.10	.19	.27	.31	.38	.42	.47	.57	.64
4½										
5	.03	.15	.24	.31	.35	.43	.48	.55	.83	.86
5½										
6	.06	.26	.40	.47	.47	.63	.68	.73	1.12	1.17
6½	.08	.37	.54	.67	.63	.78	.84	.89		
7	.15	.54	.76	.86	.82	1.07	1.14	1.21	2.35	2.48
7½	.31	1.02	1.51	1.67	1.57	1.95	1.84	2.09	3.98	4.36
8	.70	2.20	2.67	3.15	2.86	3.26	2.57	3.30	6.15	7.06
8½	.95	1.38	4.08	2.37	2.86	2.60	1.60	2 24	6.62	7.53
9	.48	.63	2.30	1.55	1.86	1.72	.69	1.53	4.50	5.12
9½	.28	.36	1.30	.95	1.17	1.08	.41	.95	1.92	2.10
10	.16	.26	.90	.65	.82	.77	.20	.73	1.43	1.56
10½	.09	.21	.74	.53	.67	.64	.12	59		
11	.06	.16	.65	.45	.61	.56	.11	.50	.77	.84
11½										
12	.01	.10	.46	.31	.45	.40	.04	.35	.50	.56
12½										
13		.05	.35	.21	.32	.28	.03	.23	.40	.46
13½										
14		.04	.28	.15	.23	.21	.02	.20	.34	.38

B line 11.15 D line 12.45 E line 14.35

Experiments with Black Oxide of Copper (CuO).

The experiments with platinum having shown the curve of radiation to be independent of the temperature, it became desirable to see how it might be affected by using different substances as sources of radiation, and whether it is also true of other substances, that the form of the curve is independent of the temperature. Accordingly, the spectra from *five* different substances, varying widely in physical and chemical properties, have been measured, each at several different temperatures. The first of these was the black oxide of copper, CuO.

In order to obtain a long and narrow radiating source of this substance, the platinum wire was coated with a saturated solution of the nitrate of copper, applied by means of a camel's-hair brush, and then a current sent through the wire. The red fumes of nitric peroxide were driven off, leaving a coating of the black oxide, which became incandescent on further heating. Quite a thick coating was applied in order to make sure that the radiation came from the oxide, and not from the platinum.

These curves, the results of eighteen series of measurements, are given in Plate III. and Table II.

TABLE II.

	Red.	Bright Red.	White.		Red.	Bright Red.	White.
2	.09	.22	.47	9	1.31	3.26	6.81
2½	.10	.23		9½	1.00	2.61	5.19
3	.12	.24	.50	10	.83	2.09	4.07
3½	.12	.28	.55	10½	.68	1.61	3.27
4	.16	.32	.65	11	.52	1.23	2.49
4½	.20	.40	.80	11½	.41	.97	1.98
5	.24	.50	.96	12	.31	.67	1.45
5½	.34	.69	1.28	12½	.24	.55	1.17
6	.40	.83	2.62	13	.16	.44	.90
6½	.51	1.01	2.02	13½	.09	.33	.76
7	.66	1.37	2.73	14	.06	.26	.62
7½	.82	1.87	3.74	14½	.08	.23	.51
8	.98	2.51	5.00	15	.08	.19	.42
8½	1.20	3.20	6.29	15½	.09	.18	.39

B line 11.15 D line 12.45 E line 14.35

The lower curve represents the distribution at a low red heat, the second at a low white, and the third at a full white heat. In this last curve the radiating substance had melted and formed a black viscous

fluid, which still clung to the wire. It will be seen that the geometrical form of the curve is the same for all of the temperatures, and even when the substance has been converted into the liquid state. These curves are the graphically constructed means of the experimental curves, as in Plate II.

TABLE III.

	Al_2O_3 p. e. = .06	Cr_2O_3 p. e. = .07	CuO. p. e. = .05	Fe_3O_4 p. e. = .07	Pt. p. e. = .04
2	.05	.35	.43	.37	.47
2½		.37	.45	.40	
3	.07	.42	.49	.46	.52
3½		.47	.55	.49	
4	.09	.52	.64	.56	.74
4½		.65	.80	.62	
5	.14	1.00	.99	.75	1.05
5½			1.28	.90	
6	.37	1.49	1.64	1.12	1.98
6½	.82	2.52	2.10	1.57	
7	1.76	4.44	2.75	2.31	4.48
7½	3.13	5.73	3 75	3.95	6.50
8	6.79	6.97	5.00	5.94	6.64
8½	6.24	6.25	6.58	6.58	
9	2.38	4.66	6.50	4.47	3.06
9½	.87	2.85	5.21	1.95	
10	.59	1.55	4.11	1.40	1.89
10½		.94	3.31	1.06	
11	.40	.78	2.51	.75	1.00
11½		.65	2.01	.60	
12	.32	.58	1.49	.48	.61
12½		.54	1.21	.42	
13	.25	.50	.96	.39	.35
13½		.46	.82	.34	
14	.16	.41	.68	.31	.26
14½		.37	.58	.30	
15	.12	.34	.49	.30	.20
15½		.30	.46	.30	

B line 11.23 D line 12.45 E line 13.86

The mean of the eighteen series of experiments is given also in Plate IV. and Table III.; all, of course, being reduced to the same value of the maximum ordinate. In fact, all of the curves of this plate are reduced in this way for convenience of comparison of their forms; their absolute size being unimportant, as no measurements of temperature were made except in the case of platinum. The curves are, of course, all reduced to the same sun spectrum, so that any of their parts are strictly comparable.

Experiments with Black Oxide of Iron (Fe_3O_4).

The wire was next coated with the black oxide of iron, which, though resembling in color the oxide of copper, is very different from it in chemical composition.

A solution of sulphate was applied with a brush, the volatile products being driven off by heating, and a coating of the Fe_3O_4 formed.

It was found that the form of the curve did not appear to vary with the temperature, and the mean of four careful series is given in Plate IV. and Table III., together with the probable error of determination of a point at the B line.

Experiments with Green Oxide of Chromium (Cr_2O_3).

The green oxide of chromium was prepared by coating the wire with chromic acid, and heating; the water was thus driven off and the higher oxides formed.

The resultant curve is shown in Plate IV. and in the accompanying table.

Experiments with White Oxide of Aluminium (Al_2O_3).

The wire was coated by applying a solution of ammonia alum, which, upon heating, was changed to Al_2O_3, the other products being volatile. The substance thus formed was hard, vitreous, and pure white.

Nine series of experiments were made at several different temperatures to see that the form of the curve was the same. The mean result is given in Table III. and Plate IV.

It now remains to see what conclusions may be drawn from a study of these curves, and a comparison of them with each other.

The curves for platinum show very plainly, and those for the other substances confirm the conclusion, that the geometrical form is nearly independent of the temperature.

The study of the radiation from copper oxide enables us to extend this conclusion to the liquid state, so that we may conclude in general that *the distribution of heat in the spectrum of a solid or liquid source of radiation is nearly independent of the temperature of the source.*

Of course this conclusion can only be accepted within the limits that the accuracy of the experiments prescribes, and it must be admitted that further researches of greater delicacy may reveal slight variations in the form of the curve.

In comparing the spectra of the different bodies with each other, we wish to study the distribution of heat, and not the relative total emission. Accordingly, the curves of Plate IV. are all reduced to approximately the same size. An examination of this plate indicates a relation which further study may show to be of considerable importance, though the experiments thus far give hardly more than a hint of what the relation is.

If we regard each curve as an irregular triangle, and, starting from each of the angles, draw lines of symmetry toward the opposite sides, the point of intersection of these lines, or, if they do not intersect in a single point, the centre of the small triangle of intersection, may be regarded as a centre of area.

The wave-lengths of these several centres of area are found to be related to the molecular weights of the radiating substances.

They are not in exactly the same proportion, but, at least, they are in the same order, so that the greater molecular weights have the greater wave-length, and large or small intervals in one quantity are represented by large or small intervals in the other.

These results appear in Table V., in which the first column gives the substances, the second the molecular weights, and the third the wave-lengths of the centres of area. In the fourth column are given the abscissas of the point in the arbitrary scale adopted in the plates.

TABLE V.

SUBSTANCES.	Molecular Weights.	Wave-Lengths of Centres.	Positions of Centres.
CuO	79.4	.00096^{mm}	9.05
Al_2O_3	102.8	.00107^{mm}	8.50
Cr_2O_3	152.4	.00124^{mm}	8.10
Fe_2O_3	160.0	.00126^{mm}	8.09
Pt	197.4	.00137^{mm}	8.04
Fe_3O_4	232.0	.00145^{mm}	7.95

It would be useless to attempt the formation of an empirical equation connecting these quantities, as the experiments so far made are not sufficiently accurate to warrant it. In fact, in single observations the centres of area near together are sometimes reversed in order. Still, the mean curves point out a relation, which could hardly be accidental for all of the six substances.

The curves are all of so nearly the same form that the distances between even the extreme geometrical centres is not very great, and

thus exceedingly delicate experiments will be necessary to determine the exact relation. Still the intervals are very much larger than the probable error of the determination of a point, so that we may feel assured of the discovery of a relation which further experiments will perhaps determine quantitatively. And we must remember, as in the other experiments, that these measurements are very small and difficult to make; and the relation here indicated may prove, upon extensive examination, to have little or no scientific value. Further and more delicate experiments upon this point are, however, contemplated.

There is another relation between the curves of Plate IV. that is of considerable interest in its bearing on the theory of exchanges. If we compare first the curve of the black substance CuO and the white substance Al_2O_3, we find the part of the former that corresponds to the luminous spectrum very much fuller than that of the latter; that is, the substance that absorbs nearly all the light rays at the ordinary temperature emits these rays most copiously when heated.

The green oxide of chromium, which is intermediate in color, and absorbs all but the green rays at the ordinary temperature, is also intermediate in its curve and emits least of all the green rays when heated. So the red oxide of iron is intermediate between the black and the green. But the curves also show us that we are not warranted in extending conclusions, drawn from observations of the luminous spectrum, to other parts.

In concluding this paper there is a strong temptation to speculate upon the meaning of the results obtained. That the geometrical form of the curve should be so nearly the same at all temperatures, and of the same *general* form for all substances, is a fact that probably must have an important physical interpretation. Does not the similarity of the curves for different substances show a similarity of movement of the ultimate components of the several substances, and so point to a similarity of ultimate composition of all matter, the slight differences in the grouping of these parts giving rise to the comparatively slight variations from the same form? Certainly this is not proof, but is it not evidence? And is it not probable that the superposition upon the radiations from the ultimate atoms, of the radiations from the groupings of these atoms, should cause the curve, as a whole, to move slightly to a shorter or longer wave-length, as the weight of a group is lighter or heavier? But I am aware that such speculations are founded on too insufficient data, and I offer these results merely as an experimental contribution to the science of radiant energy.

XII.

ON THE LIMITS OF ACCURACY IN MEASUREMENTS WITH THE MICROSCOPE.

BY PROFESSOR EDWARD W. MORLEY, OF WESTERN RESERVE COLLEGE.

Presented Oct. 9, 1878.

THE following measurements of rulings on glass, by Mr. Rogers, were made with an objective of two tenths of an inch focus, and a cobweb micrometer. For a description of the ruled plates the reader is referred to page 178 of the present volume of the Proceedings. Light was thrown on the rulings by reflection from clouds: care was taken to have the light as uniform as possible. Such care is necessary in making accurate measurements with a lens of short focus. The screw for fine adjustment was permitted to be moved only through half a revolution during the measurements. The same parts of the micrometer screw were used throughout the measurements of a band. The image of the line ruled on the plate consists of a bright central line, with a darker line on each side; the wires of the micrometer were placed on this central brighter line, and so near its apparent left-hand limit that the bright line included between the dark wire and the dark border of the image of the ruled line was the minimum visible quantity, and was the same for both wires. Care was taken not to look at the index of the micrometer until the coincidence of the wires was finally established; and also to move the wires a considerable quantity before making a second measurement, except in perhaps five cases on the third plate. In two cases the coincidence thus finally established was re-examined after the reading had been taken, on account of divergence from a previous result, and in one of these the coincidence was found to be imperfect. With this exception, the figures given are absolutely the whole of the measurements on the rulings.

Two bands on the first plate, and one each on the second and third plates, were measured twice. The probable difference of two measurements of the same interval was found to be one three hundred and fifty-nine thousandth of an inch; from which the probable error of a single measurement may be presumed to be about two millionths of an inch. It happened that thirty-five of the differences between two measurements of the same space were less than the probable difference as computed by the usual formula, and thirty-five were greater.

The measurements on the third plate were more difficult than the other, partly because the lines were too fine for the easiest work, and partly on account of fatigue. They are, therefore, less satisfactory than the measurements on the other plates. The outer lines of some bands on the second plate were also troublesome, and the results for two or three not so good as for other spaces.

Mr. Rogers made measurements of the same plates, which he prepared for publication without knowing my results, but after the original micrometer readings of my measurements had passed beyond my control. Of his measurements I know nothing at the time of writing the following tabular results. By concert with him, my results are tabulated in the form adopted by him, for ease of comparison. My numbers for the spaces measured increase in the direction of the arrows on the ruled plates, if I have made no mistake, and also my numbers of the bands. The numbers of the plates are those written on them by Mr. Rogers. In the third plate I measured only spaces composed of five of the spaces of one twenty-four hundredth of an inch as ruled; the difficulty of the measurement of so faint lines, as well as the fear of incurring a return of a certain slight difficulty with one of my eyes, from which recovery was not then complete, led me thus to abridge this part of the work. It is to be regretted that this plate was not taken in hand earlier.

The figures in the columns of individual and accumulated errors represent millionths of an inch composed of twenty-four revolutions of the screw of Mr. Rogers's ruling engine. But in the case of the fourth plate they represent hundred-thousandths of a millimetre of a similar standard.

	PLATE I.						PLATE I.													
	Band I.		Band II.		Band III.		Band IV.		Band IV.		Band V.		Band V.		Band VI.		Band VII.		Band VIII.	
Space.	Individual Errors.	Accumulated Errors.	Individual Errors.	Accumulated Errors.	Individual Errors.	Accumulated Errors.	Individual Errors.	Accumulated Errors.	Individual Errors.	Accumulated Errors.	Individual Errors.	Accumulated Errors.	Individual Errors.	Accumulated Errors	Individual Errors.	Accumulated Errors.	Individual Errors.	Accumulated Errors.	Individual Errors.	Accumulated Errors.
1	-2	-2	-3	-3	+3	+3	+11	+11	+7	+7	+1	+1	+2	+2	+2	+2	-5	-5	+8	+8
2	-6	-8	-10	-13	-10	-7	-19	-8	-14	-7	-18	-17	-16	-14	-18	-16	-18	-23	-17	-9
3	-13	-21	-13	-26	-27	-34	-15	-23	-15	-22	-21	-38	-24	-38	-22	-38	-19	-42	-23	-32
4	-8	-29	-21	-47	-16	-50	-19	-42	-23	-45	-21	-59	-25	-63	-29	-67	-28	-70	-38	-70
5	-16	-45	-26	-73	-14	-64	-27	-69	-18	-63	-33	-92	-33	-96	-33	-100	-36	-106	-39	-109
6	-23	-68	-28	-101	-31	-95	-27	-96	-27	-90	-38	-130	-33	-129	-31	-131	-39	-145	-41	-150
7	-18	-86	-16	-117	-21	-116	-22	-118	-16	-106	-28	-158	-37	-166	-25	-156	-32	-177	-32	-182
8	-27	-113	-24	-141	-29	-145	-33	-151	-30	-136	-20	-178	-22	-188	-19	-175	-26	-203	-26	-208
9	-18	-131	-26	-167	-21	-166	-20	-171	-25	-161	-17	-195	-16	-204	-12	-187	-19	-222	-21	-239
10	-7	-138	-19	-186	-20	-186	-8	-179	-13	-174	-16	-211	-14	-218	-14	-201	-13	-235	-11	-240
11	-12	-150	-14	-200	-12	-194	-3	-182	-6	-180	+7	-204	+8	-210	+4	-197	+4	-231	+5	-235
12	-12	-162	-12	-212	-9	-203	-2	-184	+1	-179	+13	-191	+17	-193	+12	-185	+18	-213	+13	-222
13	-12	-174	-6	-218	-1	-204	+15	-169	+17	-162	+19	-172	+20	-173	+27	-158	+31	-182	+31	-191
14	-2	-176	+7	-211	-5	-209	+21	-148	+22	-140	+30	-142	+29	-144	+32	-126	+26	-156	+27	-164
15	+4	-172	+12	-199	+12	-197	+26	-122	+29	-111	+26	-116	+25	-119	+29	-97	+30	-126	+36	-128
16	+15	-157	+22	-187	+23	-174	+29	-93	+28	-83	+33	-83	+31	-88	+28	-69	+30	-96	+33	-95
17	+20	-137	+27	-160	+20	-154	+32	-61	+29	-54	+28	-55	+29	-59	+25	-44	+27	-69	+29	-66
18	+19	-118	+15	-135	+26	-128	+23	-38	+20	-34	+25	-30	+23	-36	+18	-26	+29	-40	+22	-44
19	+21	-97	+20	-115	+28	-100	+27	-11	+25	-9	+20	-10	+22	-14	+13	-13	+20	-20	+24	-20
20	+18	-79	+26	-89	+28	-72	+12	+1	+5	-4	+16	+6	+11	-3	+14	+1	+16	-4	+14	-6
21	+20	-59	+25	-64	+23	-40														
22	+20	-39	+21	-43	+20	-29														
23	+17	-22	+19	-24	+20	-9														
24	+18	-4	+21	-8	+16	+7														
25	+8	-1	+3	+0	+0	+7														

SPACE.	PLATE II. Band I. Individual Errors.	PLATE II. Band I. Accumulated Errors.	PLATE II. Band II. Individual Errors.	PLATE II. Band II. Accumulated Errors.	PLATE II. Band III. Individual Errors.	PLATE II. Band III. Accumulated Errors.	PLATE III. Band I. Individual Errors.	PLATE III. Band I. Accumulated Errors.	PLATE III. Band I. Individual Errors.	PLATE III. Band I. Accumulated Errors.	PLATE IV. Band I. Individual Errors.	PLATE IV. Band I. Accumulated Errors.
1	−17	−17	− 6	− 6	+10	+10	− 5	− 5	+ 3	+ 3	+15	+15
2	− 1	−18	−10	−16	−20	−10	+ 6	+ 1	+ 6	+ 9	+ 1	+16
3	+15	− 3	+ 2	−14	− 7	−17	+ 5	+ 6	+ 8	+17	− 2	+14
4	+ 1	− 2	+ 4	−10	+10	− 7	+ 1	+ 7	− 3	+14	−10	+ 4
5	− 9	−11	−11	−21	+ 1	− 6	− 2	+ 5	+ 3	+17	+ 7	+11
6	+ 6	− 5	− 6	−27	+ 2	− 4	+12	+17	+ 6	+23	− 3	+ 8
7	+ 6	+ 1	− 7	−34	−13	−17	+ 2	+19	+ 4	+27	− 7	+ 1
8	− 9	− 8	+ 1	−33	− 7	−24	+15	+34	+16	+43	− 6	− 5
9	− 3	−11	+ 4	−29	+ 7	−17	− 2	+32	+ 3	+46	+ 5	+ 0
10	+ 1	−10	+ 1	−28	− 2	−19	− 6	+26	− 6	+40	− 1	− 1
11	− 5	−15	− 4	−32	− 8	−27	− 6	+20	− 3	+37	− 5	− 6
12	− 1	−16	+ 0	−32	+10	−17	+ 2	+22	− 4	+33	+10	+ 4
13	− 3	−19	−21	−53	− 6	−23	+ 2	+24	− 2	+31	+16	+20
14	− 4	−23	+ 3	−50	− 5	−28	+ 9	+33	+ 0	+31	− 5	+15
15	+ 5	−18	− 2	−52	− 3	−31	−14	+19	− 8	+23	−12	+ 3
16	− 4	−14	+13	−39	− 3	−34	− 5	+14	+ 0	+23	+ 2	+ 5
17	+15	+ 1	+23	−16	+12	−22	− 9	+ 5	−10	+13	−10	− 5
18	− 2	− 1	− 2	−18	+ 7	−15	− 9	− 4	− 7	+ 6	+13	+ 8
19	− 2	− 3	+ 5	−13	+ 1	−14	− 5	− 9	− 6	+ 0	+ 5	+13
20	+ 7	+ 4	+ 4	− 9	+11	− 3	+12	+ 3	+ 3	+ 3	−12	+ 1
21	− 1	+ 3	+ 1	− 8	+ 3	+ 0						
22	− 2	+ 1	− 6	−14	− 5	− 5						
23	− 1	+ 0	+ 1	−13	+ 4	− 1						
24	+ 6	+ 6	+ 5	− 8	+ 0	− 1						
25	− 4	+ 2	+ 2	− 6	− 1	− 2						

XIII.

ON THE LIMITS OF ACCURACY IN MEASUREMENTS WITH THE TELESCOPE AND THE MICROSCOPE.

BY PROFESSOR WILLIAM A. ROGERS.

Presented Oct. 9, 1878.

IT is often desirable in astronomical observations to assign to a given result the degree of precision which the observations will justify. Usually the limit of precision is defined either by the probable error of a single observation, or of the mean of a given number of observations.

Let

$x =$ any given numerical value.

$n =$ the number of values of x.

$v =$ the difference between each value of x and the arithmetical mean of all the values.

$[v] =$ the sum of the separate residuals, without regard to sign.

$r =$ the probable error of a single value.

$r_0 =$ the probable error of the arithmetical mean.

We shall then have, —

$$r = .6745\sqrt{\frac{[v\,v]}{m-1}} \qquad (a)$$

$$r_0 = .6745\sqrt{\frac{[v\,v]}{m\,(m-1)}}$$

Or, according to Peters, —

$$r = .8453\ \frac{[v]}{\sqrt{m\,(m-1)}} \qquad (b)$$

$$r_0 = .8453\ \frac{[v]}{m\sqrt{(m-1)}}$$

As an illustration, we assume the following values of x, *without defining their signification*: —

x	v	$v v$
61″.70	+ ″.05	+ ″.02
61.50	+ .25	+ .06
60.90	+ .85	+ .72
61.70	+ .05	+ .02
61.30	+ .45	+ .20
61.20	+ .55	+ .30
60.80	+ .95	+ .90
61.90	— .15	+ .02
61.60	+ .15	+ .03
61.50	+ .25	+ .06
62.80	— 1.05	+ 1.10
62.70	— .95	+ .90
60.80	+ .95	+ .90
61.30	+ .45	+ .20
63.00	— 1.25	+ 1.56
61.10	+ .65	+ .42
63.90	— 2.15	+ 4.62
Mean, 61.75		

From equations (a) we have, —

$$r = \pm .6745\sqrt{\frac{12.03}{16}} = \pm .585''$$

$$r_0 = \pm .6745\sqrt{\frac{12.08}{16 \times 17}} = \pm .142''$$

And from equations (b), —

$$r = \pm \frac{.8458 \times 11.15}{\sqrt{17 \times 16}} = \pm .571''$$

$$r_0 = \pm \frac{.8453 \times 11.15}{17\sqrt{16}} = \pm .139''$$

If we reject the last value of x, viz. 63″.90, we have: —

From (a), —

$$r = \pm .474''$$
$$r_0 = \pm .119$$

From (b), —

$$r = \pm .491$$
$$r_0 = \pm .123$$

Let us now inquire wha: interpretation can be safely given to these

values of r and r_0, and what conclusions can be drawn therefrom concerning the precision of x.

First, it will be seen that the two formulæ do not give precisely the same results, and the relation between the results is changed by rejecting one apparently discordant observation. The difference is, however, insignificant when compared with the actual error of observation. In general, the agreement will be more perfect the greater the number of values of x.

Second, it is obvious that if for x we write, $x \pm$ a constant, the values of v will not be thereby changed; hence the values of r and r_0 *will give no indication whatever with reference to the existence of any constant error involved in the values of x.*

Admitting, then, that there is no constant error in the given series, what degree of precision can be assigned to any single value of x, and to the mean value 61″.75?

It would hardly seem necessary to call attention to the erroneous assumption that, since the value of r is $\pm$ .57″, therefore no single value can be greater than 62″.32, nor less than 61″.18; or that since r_0 is $\pm$ .14″, therefore the value 61″.75 is true within this limit. The refutation of the first assumption is made sufficiently easy by an examination of the separate values of x, but it is not quite so easy to show the fallacy of the second.

Notwithstanding the absurdity of attempting to assign to the arithmetical mean the degree of precision indicated by the value of r_0, observers of limited experiences are continually found doing this, and the writer recalls two instances in which professional astronomers have committed themselves to the same fallacy.

In general, it is entirely unsafe to draw conclusions with respect to the degree of precision to be attached to the arithmetical mean from the magnitude of the probable error, until the signification of the values from which it is derived is defined.

If the values of x are found by successive readings of the four microscopes of a meridian circle for the same position of the telescope, the separate values are *simple functions* of the quantity required, and involve only the accidental errors of the observer, either in making the bisections of the divisions of the circle, or in reading the index of the micrometer screws. In this case the probable error of the mean is a tolerably accurate indication of the degree of precision which may be attached to it.

But the values of x given, represent the observed index errors of the meridian circle of Harvard College Observatory, as derived from

separate fundamental stars, observed January 5, 1872. They are given on page xxiii., Vol. X., of the Annals of the Observatory. Here x is a *complex function*. It involves not only the error of reading the microscopes, but several other *classes* of errors. They may be enumerated as follows: —

Errors depending on the observer.	(*a*) Error of reading microscopes. (*b*) Error of bisection of the star observed, or its equivalent.
Errors depending on the instrument.	(*c*) Errors of graduation of the circle, both accidental and systematic. (*d*) Error depending on the micrometer screws of microscopes. (*e*) Error due to the flexure of the instrument. (*f*) Error due to an imperfect figure of the pivots. (*g*) Error resulting from a change in the position of the instrument during the observations.
Errors independent of the observer and of the instrument.	(*h*) Error resulting from an erroneous place of the fundamental star observed. (*i*) Error depending on the state of the atmosphere, including the constant of refraction, imperfect thermometers, barometers, &c.

In this case, then, one must place quite a different interpretation upon the probable error of the mean value. In fact, the only safe interpretation that can be given to it, is the one which regards it as a means of comparing observations made by different observers under nearly the same conditions and in the same manner.

This subject may be considered in another way. It is a property of the arithmetical mean that it makes the sum of the squares of the residuals a minimum. The solution of a greater number of equations than the unknown quantities which they contain, by the process of least squares, rests upon the same basis; viz. that such values must be given to the unknown quantities as will, when substituted in the original equations, make the sum of the squares of the residuals a minimum. Theoretically, any unknown quantity may be made equal to a constant plus the sum of all the corrections which make up this quantity. We may always have

$$X = C + A a + B b + C c + D d, \text{ \&c.}$$

The only limit to the number of terms is the one which requires that the coefficients A, B, C, D, &c. shall be known. The solution of a series of equations of this form will give the most probable values of the constant C, and of the unknown quantities a, b, c, d, &c., provided

x is a simple function; but if x is a complex function the solution will no longer give the *true* values of the separate unknown quantities, though it may yield such values as will give the most probable sum of Aa, Bb, Cc, Dd, &c., with respect to their effect upon x.

Let us take, as an illustration, the ordinary equation for the reduction of transit observations. The fundamental equation may be put under the following variety of forms: —

$$
\begin{array}{ll}
(a) & 0 = \Delta\mathrm{T} + [T - \mathrm{R.\,A.}] + Aa \\
(b) & = \Delta\mathrm{T} + [T - \mathrm{R.\,A.}] + Aa + Bb \\
(c) & = \Delta\mathrm{T} + [T - \mathrm{R.\,A.}] + Aa + Bb + Cc \\
(d) & = \Delta\mathrm{T} + [T_0 - \mathrm{R.\,A.}] + \tau h + Aa + Bb + Cc \\
(e) & = \Delta\mathrm{T} + [T_0 - \mathrm{R.\,A.}] + \tau h + Aa + Bb + Cc + Dd \\
(f) & = \Delta\mathrm{T} + [T_0 - \mathrm{R.A.}_0] + Ee + \tau h + Aa + Bb + Cc + Dd \\
(g) & = \Delta\mathrm{T} + [T_0 - \mathrm{R.A.}_0] + Ee + \tau h + Aa + Bb + Cc + Dd + C
\end{array}
$$

If the level b and the collimation c are obtained independently of the observations by direct measures, then, neglecting the small terms which follow, for any time, T, and with the given right ascension, R. A., the only unknown quantities in equation (a) are the clock error ΔT and the azimuth term Aa. A solution of a series of equations of this form will give the most probable *individual* values of a and ΔT.

If the level term Bb is unknown, the general equation takes the form (b). Notwithstanding the fact that the equation is somewhat more complex in its structure, the solution by least squares will give the most probable individual values of a and b, if the stars are selected with reference to a proper distribution of positive and negative values for A and B.

If the collimation term Cc is unknown, the equation takes the form (c). Here a solution by least squares will *not* give the most probable individual values of a, b, and c, unless the observations are arranged with proper reference both to the magnitude and the sign of A, B, and C. Even when these precautions are observed, the value of c from the solution will rarely agree exactly with the value obtained from reversal or from collimators.

If, for any star, the observed time T is written $T_0 + \tau h$, the term τh being the hourly rate of the clock multiplied by the interval τ between T and T_0, the equation takes the form (d). We now introduce an unknown quantity depending on another instrument, viz. the clock.

We may still further introduce the term $D\,d$, representing the diurnal aberration, giving the form (*e*), and by substituting R. $A._0 + E\,e$ for R. A. where $E\,e$ represents a term depending on 2 ☽, we get the form (*f*).

Finally, if we represent by the constant C the personal equation between bright and faint wires, bright and faint stars, &c., we have the form (*g*).

Of course it is wholly absurd to introduce the terms $D\,d$, $E\,e$, and C as unknown quantities, and these forms are given only to show that one must exercise sound judgment in the formation of the equations in order that the solution by least squares shall give correct results. It is useless to expect that the solution will separate errors which appertain to different instruments. For example, in form (*g*) it would seem hardly necessary to say that the solution will entirely fail in assigning to the telescope the correct values of a, b, and c; to the clock, the true values of ΔT and $\tau\,h$, to yield the physical constant which enters into the diurnal aberration, and the coefficient which results from the variable motion of the moon; and to refer to the observer the constant which involves the various forms of personal equation. Yet, according to the common acceptation of the theory, this form of the equation is allowable, since all the unknown quantities have known coefficients.

Again, as soon as the equation involves unknown quantities which pertain to different instruments, it becomes so complex in its character that we can no longer assume that even the *sum* of the terms which affect ΔT is the most probable value that can be found, for in so doing we assume that ΔT is a constant, whereas the solution requires it to be a variable.

Let us now inquire how far these views are confirmed by the facts of observation.

In my own case, the probable error of a *single* reading of four microscopes of the meridian circle is $\pm.094''$. If, therefore, as many as 10 observations are obtained, the probable error of the mean will be not far from $\pm.03''$. The probable error of a single difference between myself and my assistant, Mr. Joseph F. MacCormick, is for a single reading of four microscopes $\pm.125''$.

The probable error of a *single* complete observation in declination is, in my own case, about $\pm.36''$, and of the mean of 10 observations is $\pm.11''$. The probable error of a *single* complete observation in right ascension is, for an equational star, $\pm.026^s$ and for the mean of 10 observations $\pm.008^s$.

If, therefore, the probable error can be taken as a measure of the accuracy of the observations, there ought to be no difficulty in obtaining, from a moderate number of observations, the right ascension within $.02^s$ and the declination within $0''.2$. Yet it is doubtful, after continuous observations in all parts of the world for more than a century, if there is a single star in the heavens whose absolute co-ordinates are known within these limits. In 1866 the illustrious Argelander proposed a list of stars for simultaneous observation by different observers, for the purpose of investigating the systematic differences which he found to exist in all modern catalogues. This scheme was carried out only to a limited extent. But in 1878 the fortunate requirements of a special problem secured data which will go far towards the establishment of the existence of these errors, even with the present methods of refinement in observation, if indeed they do not for the present reveal their cause.

During that year Mr. David Gill, recently appointed Director of the Cape of Good Hope Observatory, solicited the co-operation of astronomers in determining the co-ordinates of 28 stars, which he used in his heliometer observations of the planet Mars for obtaining the solar parallax. The observatories named below made the observations required, which were forwarded to Mr. Gill upon the completion of the reductions. The results are published in Vol. XXXIX., page 99, of the Monthly Notices of the Royal Astronomical Society.

In the following table are given the differences between the least and the greatest results for each star, both in right ascension and in declination.

STAR.	$\Delta\alpha$	$\Delta\delta$	STAR.	$\Delta\alpha$	$\Delta\delta$	STAR.	$\Delta\alpha$	$\Delta\delta$
	s.	"		s.	"		s.	"
1	0.189	1.45	10	0.460	2.84	19	0.242	3.14
2	.169	2.04	11	.287	1.77	20	.333	2.70
3	.377	2.63	12	.077	1.74	21	.220	2.16
4	.098	2.57	13	.350	1.80	22	.283	2.31
5	.224	2.04	14	.263	2.34	23	.260	1.77
6	.166	1.86	15	.270	1.80	24	.203	2.78
7	.193	3.47	16	.183	1.86	25	.219	1.62
8	.190	1.93	17	.225	3.47	26	.207	2.06
9	.300	3.15	18	.287	1.37	27	.298	2.57
						28	.264	2.47

Even after the observations were reduced to a homogeneous system, Mr. Gill finds the following outstanding errors: —

Authority.	$\Delta\alpha$	$\Delta\delta$	Authority.	$\Delta\alpha$	$\Delta\delta$
	s.	″		s.	″
Königsberg,	+.005	—0.71	Leiden,	—.053	—0.19
Melbourne,	+.026	—0.49	Paris,	+.055	+0.01
Pulkowa,	+.005	+0.36	Washington,	—.120	+0.78
Leipzig,	+.049	+0.40	Harvard College,	—.072	+0.09
Greenwich,	+.009	—0.56	Cordoba,	—.032	—0.20
Berlin,	+.044	+0.67	Oxford,	+.076	+0.21

These systematic discordances, especially in right ascension, are so alarmingly large that, unless they can be reconciled, the heliometer observations are comparatively worthless. Mr. Gill, therefore, proposed a second list of 12 stars, one half comparatively bright and the other half faint. The observations of these stars are now completed, but the only series yet at hand, are those of Königsberg and Harvard College. Here the discordance is very large, and varies with the magnitude of the star observed. Professor Pickering, the Director of Harvard College Observatory, early in this investigation, proposed the artificial reduction of the magnitude of the bright stars by holding circular diaphragms of varying diameters in front of the object-glass of the telescope. By alternating between bright and faint images of the same star, on different groups of the transit threads, the personal equation between bright and faint stars can be found. This plan was followed in the investigation at Harvard College Observatory, at Leiden, and probably at some other observatories. At Harvard College Observatory, also, a sensible difference was found between results obtained with bright and faint fields of the telescope, this difference varying with the magnitude of the star.

A similar investigation is now being made in another class of observations, viz. the measurement of the position angle and distance of double stars with the filar-micrometer. The range of systematic discordances between the measures of different observers is of course here far less than will always be found in the determination of position in space, for such observations are entirely relative in their character; but the outstanding errors are still so large as to demand a special investigation. Even with observers of skill and long experience, such as Struve, Hall, Dembowski, Burnham, and Stone, there are residual errors in the measurements of the same components far exceeding the limits indicated by the magnitude of the probable error of any single observer.

Finally, it is even an open question whether any real advance has

been made in the absolute precision of observations with the telescope for the last forty years, if we except the tentative investigations of the last five or six years. Argelander's Åbo Catalogue of 1830, and the Pulkowa Catalogue of 1845, are as yet pre-eminent for that kind of accuracy which answers to the crucial test of agreement with future observations. After a lapse of nearly fifty years, Argelander's positions of the thirty-six stars known as the "Maskelyne fundamental stars" are at least as near the truth as the mean of the observations of these stars made during the last ten years.

The great need of instrumental astronomy is a rigid investigation of all the classes of error to which observations are now subject, not simply for any one observer, but for all the principal observers of the world, and *upon a common plan.* If some competent and recognized authority, like the *Astronomischen Gesellschaft*, would arrange a scheme of observations having this object in view, and take measures to secure the co-operation of all the principal observatories in this work, it would seem that the foundation for a real advance might be made in the precision with which observations can be made.

In the investigation which follows I have endeavored to ascertain the limits of accuracy in measurements with the microscope by a process similar to that by which observers with the telescope are now seeking to reach the ultimate limit of precision. The remarks already made with regard to the degree of reliability to be attached to conclusions drawn from the magnitude of the probable errors of observation apply with equal force to measures made under the microscope. Neither the probable error of a single observation nor the probable error of the mean of a given number of observations furnishes a safe criterion by which the real measure of accuracy may be estimated. For example, with the comparator for short lengths described in the April number of the *American Quarterly Microscopical Journal*, it is the experience of the writer that, in an unlimited number of repetitions of measures of the same space, the pointer will in every case fall upon the same tenth of a division of the index of the screw. Hence, if the readings are taken to tenths only, the resulting probable error will always be zero, without regard to the value of one division. In this particular instrument the value of one tenth of one division is one eighty-thousandth of an inch, but the probable error would still remain zero if the readings were carried to tenths of one division only for any change whatever in the pitch of the screw, and consequently for any reduction in the value of one division, provided the pointer always falls within this tenth.

The probable error of a *single* measure with the comparator for short lengths is about two millionths of an inch. If the probable error can be taken as a measure of precision, it ought not to be difficult to measure one millionth of an inch with entire certainty by repeating the measures a sufficient number of times.

Let us see if this theoretical accuracy is attainable. Before proceeding to the discussion, it may be worth while to say that a sharp distinction must be drawn between absolute accuracy and a superficial appearance of accuracy. If I determine the value of a centimeter within one ten-thousandth of its whole length, I can use the equivalent expression, one millionth of a meter; but it does not follow that I can measure a meter within this limit. I say that a given space, corresponding to one thousandth of an inch, requires a correction of one millionth of an inch; but it makes a wide difference whether I ascertain this fact by direct measurement, or whether I get it by dividing the correction for an entire inch by one thousand. Extending the number of figures in the quotient does not give a corresponding increase of accuracy. The index of the screw of my dividing engine can be set to correspond to a motion of one billionth of an inch with entire certainty as far as the mechanical indication of this degree of accuracy is concerned; yet previous to May, 1877, the actual errors of a given ruled plate amounted, under certain conditions, to as much as one seven-thousandth of an inch. Even now, after four epochs of improvement, I can hardly say of a given space that it is certainly true within one eighty-thousandth of an inch until a careful investigation has been made with the comparator. Again, it does not follow that, because the spaces of a closely ruled band of lines, like Nobert's bands, appear to be equal under an objective of high power, they are therefore to be taken as the measure of the real accuracy of the graduations. It is far more difficult to subdivide an inch into one hundred equal parts, than to make a further subdivision of one of these parts. As I shall presently show, almost all of the errors of a given graduation are periodic in their character, but the increments proceed by such minute variations in the case of closely ruled bands that they can only be detected when their sum amounts to an appreciable quantity Thus, if the accumulated error of a screw having a pitch of one in twenty amounts to one two-thousandth of an inch for half a revolution of the index, the average periodic error for each two-thousandth of an inch will be one hundred-thousandth of an inch. It will thus be seen that, for even the first of Nobert's bands, which are about ten thousand to the inch, the systematic error for any single space is inap-

preciable. But even in this case, only ten increments are required in order to produce an error of measurable magnitude.

A simple and direct way to determine the degree of precision with which measures under the microscope may be made, is to compare measurements of the same space made by different observers and under different conditions. I may get results which show an agreement *inter se* quite within the limits of the accuracy required, but which are yet wide of the truth. But if another equally skilful observer obtains substantially the same results from a series of measurements made under entirely different conditions, the inference of their general correctness may be drawn with tolerable safety.

In carrying forward this investigation I was fortunate in securing the co-operation of Professor Edward W. Morley, of Hudson, Ohio, whose paper will be found on page 164 of this volume of the Proceedings.

The rulings selected for joint measurement, are described as follows: —

Plate I. consists of eight bands. The first three bands are composed of twenty-six lines each. The distance between the lines is $\frac{1}{480}$ of an inch. The remaining five bands are composed of twenty-one lines each, the distance between the lines being $\frac{1}{800}$ of an inch. *All the rulings of this plate involve the periodic errors which belong to the ruling screw.*

Plate II. consists of three bands of very heavy lines, each band being composed of twenty-six lines. The interval between the lines is the same as in the corresponding three bands of Plate I. The lines are filled with graphite and are mounted in balsam. *In this plate the errors which are a function of one revolution of the screw were corrected during the process of ruling.*

Plate III. consists of 101 lines, separated by an interval of $\frac{1}{2400}$ of an inch, *and freed as nearly as possible from errors of all kinds.*

Plate IV. consists of 21 lines, separated by an interval of $\frac{1}{20}^{mm.}$, *corrected for systematic errors.*

The results given in the following tables under the head "Corr." represent the corrections which must be applied to each space of a given band in order to make it equal to a mean of all the spaces. They are *expressed in millionths of an inch*, except in Plate IV., in which the unit is *one hundred-thousandth of a millimeter*. The results given under the head Σ represent the accumulated errors reckoned from the first line of each band. In Plate I. the values given were formed by successive additions of the individual errors. In Plates II.,

III., and IV., the values in column Σ were obtained by measuring the accumulated errors directly with the comparator for short lengths, and the individual errors were found by successive subtractions.

The first band of Plate I. was measured with great care with a filar-micrometer made by Powell and Leland, with a glass eye-piece micrometer, with a comparator screw by Merz of Munich, and with the Clark screw mentioned above. The results from the Clark screw are somewhat discordant, as they were obtained before the instrument was fairly completed. They are, however, taken into account on the principle adopted of including *every* measure taken. The values of Plate III. were found by taking the mean of the accumulated errors of each successive group of five spaces, measured directly with the Clark comparator for short lengths. The separate results given under the first and fourth bands of Plate I. are given for the purpose of deducing the probable error of observation. They are not simple repetitions of measures made at one time. Each column refers to a different date. As the different sets of measures were only brought together from the note-books after all the work was done, I had no previous knowledge of the degree of agreement to be expected from separate measures of the same space. In fact, the comparison was made for the first time, soon after receiving the results communicated by Professor Morley.

PLATE I.—BAND I.

Space.	Corrections to each Space from Measures with Eye-piece Micrometer and ¼-inch Objective.						Corrections to each Space from Measures with Merz Screw and ¼-inch Objective.					Correction to each Space from Measures with Filar Micrometer and ¼-inch Objective.		Correction to each Space from Measures with Clark Screw.	
	I.	II.	III.	IV.	Mean Corr.	Σ	I.	II.	III.	Mean Corr.	Σ	Corr.	Σ	Corr.	Σ
1	+3	−4	−6	+6	+0	+0	−8	−20	−6	−11	−11	+5	+5	−12	−12
2	−2	−4	−8	−14	−7	−7	−9	−6	−9	−8	−19	−11	−6	−13	−25
3	−14	−7	−11	−17	−12	−19	−17	−22	−11	−17	−36	−20	−26	−8	−33
4	−17	−18	−9	−17	−15	−34	−11	−21	−11	−14	−50	−13	−39	−23	−56
5	−19	−17	−14	−20	−18	−52	−25	−18	−16	−20	−72	−14	−53	−14	−70
6	−25	−25	−26	−23	−25	−77	−24	−16	−20	−20	−92	−28	−81	−28	−98
7	−25	−29	−21	−20	−24	−101	−28	−18	−16	−21	−113	−26	−107	−24	−122
8	−27	−27	−29	−26	−27	−128	−28	−18	−27	−24	−137	−24	−131	−11	−133
9	−22	−26	−25	−17	−25	−153	−21	−28	−30	−26	−163	−22	−153	−37	−170
10	−23	−14	−29	−17	−21	−174	−19	−14	−25	−19	−182	−18	−171	−8	−178
11	−21	−10	−21	−20	−18	−192	−5	−19	−12	−12	−194	−15	−186	−12	−190
12	−9	−8	−10	−11	−10	−202	+9	+0	−11	−1	−195	−7	−193	−11	−201
13	−12	−7	−8	−6	−8	−210	+23	−4	−3	+5	−190	+1	−192	+3	−198
14	+6	−1	+4	+6	+4	−206	+7	−4	+6	+3	−187	+6	−186	+8	−190
15	+9	+13	+8	+6	+9	−197	+0	+0	+9	+3	−184	+7	−179	+5	−185
16	+16	+18	+19	+12	+16	−181	+10	+16	+9	+12	−172	+12	−167	+17	−168
17	+21	+19	+22	+12	+19	−162	+16	+11	+11	+13	−159	+15	−152	+34	−134
18	+21	+21	+22	+18	+21	−141	+13	+26	+15	+18	−141	+16	−136	+7	−127
19	+25	+22	+22	+27	+24	−117	+20	+30	+29	+26	−115	+20	−116	+28	−99
20	+23	+23	+25	+24	+24	−93	+22	+30	+21	+24	−91	+25	−91	+20	−79
21	+23	+20	+24	+30	+24	−69	+23	+30	+28	+27	−64	+31	−60	+32	−47
22	+23	+23	+25	+27	+24	−45	+25	+25	+31	+27	−37	+21	−39	+12	−35
23	+16	+17	+19	+18	+18	−27	+12	+20	+18	+17	−20	+13	−26	+9	−26
24	+18	+17	+22	+18	+18	−9	+21	+15	+19	+18	−2	+21	−5	+26	−0
25	+7	+3	+3	+6	+5	−4	+0	+0	+0	+0	−2	+5	+0	+0	−0

PLATE I.

Space.	Band II. Corr.	Band II. Σ	Band III. Corr.	Band III. Σ	Band IV. I.	Band IV. II.	Band IV. III.	Band IV. Mean Corr.	Band IV. Σ	Filar Micrometer. Corr.	Filar Micrometer. Σ	Band V. Corr.	Band V. Σ	Band VI. Corr.	Band VI. Σ	Band VII. Corr.	Band VII. Σ	Band VIII. Corr.	Band VIII. Σ
1	+ 0	+ 0	+ 1	+ 1	+21	+14	+14	+16	+ 16	+19	+ 19	+ 7	+ 7	+ 4	+ 4	+ 4	+ 4	+ 3	+ 3
2	−11	− 11	− 6	− 5	− 2	− 7	−10	− 6	+ 10	− 7	+ 12	−12	− 5	−11	− 7	−13	− 9	−10	− 7
3	−18	− 29	−21	− 26	−17	−10	−22	−16	− 6	−14	− 2	−23	− 28	−17	− 24	−17	− 26	−18	− 25
4	−20	− 49	−19	− 45	−19	−25	−13	−19	− 25	−22	− 24	−33	− 61	−23	− 47	−27	− 53	−27	− 52
5	−24	− 73	−26	− 71	−28	−28	−33	−30	− 55	−34	− 58	−35	− 96	−32	− 79	−36	− 89	−37	− 89
6	−30	−103	−28	− 99	−32	−31	−33	−32	− 87	−34	− 92	−35	−131	−33	−112	−35	−124	−39	−128
7	−26	−129	−26	−125	−26	−27	−31	−28	−115	−25	−117	−31	−162	−29	−141	−32	−156	−30	−158
8	−24	−153	−29	−154	−29	−31	−33	−31	−146	−33	−150	−25	−187	−28	−169	−31	−187	−24	−182
9	−27	−180	−26	−180	−22	−23	−25	−23	−169	−24	−174	−18	−205	−19	−188	−23	−210	−23	−205
10	−22	−202	−25	−205	−11	−12	−10	−11	−180	−15	−189	−15	−220	−15	−203	−13	−223	− 9	−214
11	−16	−218	−17	−222	+ 0	− 7	+ 2	− 2	−182	+ 1	−188	+ 1	−219	+ 8	−195	− 2	−225	+ 2	−212
12	−11	−229	− 7	−229	+ 3	+ 6	+ 8	+ 6	−176	+ 4	−184	+16	−203	+10	−185	+15	−210	+12	−200
13	− 3	−232	− 1	−230	+15	+19	+20	+18	−158	+21	−163	+22	−181	+20	−165	+26	−184	+28	−172
14	+ 6	−226	− 1	−231	+20	+21	+20	+20	−138	+27	−136	+24	−157	+29	−136	+30	−154	+26	−146
15	+13	−213	+17	−214	+20	+28	+23	+24	−114	+26	−110	+27	−130	+28	−108	+29	−125	+34	−112
16	+23	−190	+20	−194	+27	+32	+32	+30	− 84	+33	− 77	+30	−100	+28	− 80	+30	− 95	+34	− 78
17	+27	−163	+25	−169	+29	+28	+29	+29	− 55	+29	− 48	+31	− 69	+27	− 53	+29	− 66	+27	− 51
18	+23	−140	+27	−142	+21	+29	+26	+25	− 30	+22	− 26	+26	− 43	+28	− 25	+27	− 39	+25	− 26
19	+19	−121	+25	−117	+21	+20	+23	+21	− 9	+21	− 5	+25	− 18	+19	− 6	+22	− 17	+21	− 5
20	+24	− 97	+27	− 90	+ 6	+ 6	+14	+ 9	+ 0	+ 5	+ 0	+17	− 1	+ 7	+ 1	+14	− 3	+ 8	+ 3
21	+22	− 75	+22	− 68															
22	+24	− 51	+24	− 44															
23	+23	− 28	+22	− 22															
24	+21	− 7	+19	− 3															
25	+ 6	− 1	+ 4	+ 1															

Space.	Plate II.						Plate III.		Plate IV.	
	Band I.		Band II.		Band III.		Band I.		Band I. = $\frac{1}{50}$ mm.	
	Corr.	Σ	Corr.	Σ	Corr.	Σ	Corr.	Σ	Corr.	Σ
1	+ 2	+ 2	− 6	− 6	− 3	− 3	+3	+3	+10	+10
2	− 4	− 2	− 1	− 7	+ 8	+ 5	+0	+3	−11	− 1
3	− 4	− 6	− 1	− 8	+ 3	+ 8	+0	+3	+ 0	− 1
4	+ 3	− 3	+ 4	− 4	−15	− 7	−4	−1	− 7	− 8
5	+ 3	+ 0	− 6	−10	+21	+14	+3	+2	+ 2	− 6
6	− 6	− 6	+ 1	− 9	+ 8	+22	−5	−3	+ 1	− 5
7	− 6	−12	+ 0	− 9	−22	+ 0	−1	−4	+ 3	− 2
8	−10	−22	− 8	−17	+ 9	+ 9	−2	−6	+ 2	− 0
9	+ 0	−22	− 2	−19	− 7	+ 2	−1	−7	+ 2	+ 2
10	+ 1	−21	− 8	−27	− 6	− 4	+0	−7	+ 5	+ 7
11	− 2	−23	− 5	−32	+ 9	+ 5	+0	−7	− 2	+ 5
12	− 8	−31	+ 3	−29	− 1	+ 4	+1	−6	+ 2	+ 7
13	+ 8	−23	+15	−14	− 6	− 2	+1	−5	+14	+21
14	+ 2	−21	− 5	−19	− 1	− 3	+1	−4	−17	+ 4
15	+ 0	−21	− 6	−25	+ 1	− 2	+5	+1	− 2	+ 2
16	+ 6	−15	+ 6	−19	+ 6	+ 4	+2	+3	− 1	+ 1
17	+ 9	− 6	− 2	−21	− 8	− 4	−6	−3	+ 0	+ 1
18	− 9	−15	+ 4	−17	+ 6	+ 2	+6	+3	+ 8	+ 8
19	+ 5	−10	+12	− 5	+ 1	+ 3	−1	+2	+ 0	+ 8
20	+10	+ 0	+ 4	− 1	+ 2	+ 5	+1	+3	−10	− 2
21	+ 0	+ 0	− 4	− 5	+12	+17				
22	+ 0	+ 0	− 1	− 6	− 5	+12				
23	+ 0	+ 0	− 4	−10	− 6	+ 6				
24	+ 2	+ 2	− 2	−12	− 8	− 2				
25	− 2	+ 0	+12	+ 0	+ 0	− 2				

From a comparison of the separate values obtained by myself and by Professor Morley, the following conclusions are drawn: —

(*a*) By comparing the separate values of Bands I. and IV. of Plate I., obtained with the eye-piece micrometer, with the corresponding mean values, the average probable error of the measure of a single space is found to be 19 ten-millionths of an inch, the greatest deviation from the mean in 156 measures being 8 millionths of an inch.

(*b*) Comparing with the mean value, the separate results obtained with the eye-piece micrometer, the Merz screw, and the filar micrometer, from the first and fourth bands of Plate I. we find the following average deviations: —

For the eye-piece micrometer, 17 ten-millionths of an inch.
For the Merz screw, 25 ten-millionths of an inch.
For the filar micrometer, 18 ten-millionths of an inch.

(*c*) Comparing the measures of the separate spaces made by Professor Morley with my own, made in the first band of Plate I. with

the eye-piece micrometer, the Merz screw, and the filar-micrometer, and in the remaining bands of this plate with the eye-piece micrometer only, we find the following deviations expressed in millionths of an inch: —

Number of millionths,	0	1	2	3	4	5	6	7	8	9	10	11	12
Number of cases of agreement,	16	30	39	24	15	17	13	8	2	3	4	2	2

The mean deviation is 34 ten-millionths of an inch.

(*d*) Comparing the accumulated errors of the middle point obtained by Professor Morley and by myself, we have: —

	Band.	Rogers.	Morley.	R. — M.
Plate I.	1	—197	—174	—23
	2	—232	—218	—14
	3	—230	—204	—26
	4	—181	—177	— 4
	5	—219	—211	— 8
	6	—199	—199	+ 0
	7	—224	—233	+ 9
	8	—213	—237	+24
Plate II.	1	— 23	— 19	— 4
	2	— 14	— 53	+39
	3	— 2	— 23	+21
Plate III.	1	— 7	+ 31	—38

The numerical value of the average deviation is therefore 17 millionths of an inch. It is to be noted, however, that only the bands of Plate I. are strictly comparable, since these only were obtained in the same way, viz. by successive additions. The values for Plates II. and III., it will be remembered, were obtained in my own case by direct measurement, in which the degree of accuracy may be taken as nearly equal to that of the measure of any individual space, while those of Professor Morley were obtained by direct addition, in which case an error at any point is carried through the whole of the remaining series.

(*e*) In explanation of the disagreement in the maximum values of the accumulated errors, even in the bands of Plate I., which were ruled at the same time, it is to be said that the graduation was done before I had learned the necessity of dispensing with oil or grease as

a lubricant. Without doubt, a part of the discordance is due to errors of measurement, but recent experience has convinced me that, when oil is used as a lubricant, every precision-screw has a variable periodic error, depending on the position of the nut in the line of its motion, especially when there is a decided change of temperature. It is sufficient to say here, that, since adopting a substitute for oil, the errors of the screw have remained practically constant.

(f) It will be seen from simple inspection that nearly all of the errors under discussion are periodic in their character. This may be shown conclusively in the following way: —

If we have a series of errors depending on one revolution of the screw, which are *strictly periodic in their character*, and from which all accidental errors are excluded, the given series can be represented *exactly* by a series of equations of the form, —

$$n = + a \sin x + b \cos x + a' \sin 2x + b' \cos 2x, \text{ \&c.};$$

in which

n represents any given value of the series;
x is an aliquot part of one revolution of the screw;
a, b, a', b', are unknown coefficients.

If, therefore, an expression of this form is found which will represent all the given errors of a series, it may be safely affirmed that the errors themselves are entirely periodic in their character.

Making n equal, successively, to the mean of the values of the individual errors of spaces 1, 2, 3, &c. of the first three bands of Plate I., we have a series of equations whose solution by least squares will give the normal equation,

$$n = -26.6 \sin x + 5.9 \cos x - 0.1 \sin 2x + 0.8 \cos 2x.$$

In like manner we get from the mean of the separate values of Bands IV., V., VI., VII., VIII. of the same plate,

$$n = -29.1 \sin x + 9.9 \cos x - 2.0 \sin 2x + 1.3 \cos 2x.$$

Substituting in these equations the known values of x, we get values of n which are directly comparable with the observed values given in the tables. The observed and the computed values are given in the following table, as well as the deviations of both the individual and the accumulated errors from the computed values.

Plate I.—Bands I., II., III.					
Individual Errors.			Accumulated Errors.		
Observed value of n.	Computed value of n.	Δ	Observed.	Computed.	Δ
— 1	+ 0	—1	— 1	+ 0	—1
— 9	— 8	—1	— 10	— 8	—2
—18	—14	—4	— 28	— 22	—6
—19	—19	+0	— 47	— 41	—6
—23	—24	+1	— 70	— 65	—5
—27	—28	+1	— 97	— 93	—4
—25	—28	+8	—122	—121	—1
—25	—27	+2	—147	—148	+1
—27	—25	—2	—174	—173	—1
—21	—21	+0	—195	—194	—1
—16	—15	—1	—211	—209	—2
— 8	— 8	+0	—219	—217	—2
— 1	— 2	+1	—220	—219	—1
+ 4	+ 6	—2	—216	—218	—8
+12	+12	+0	—204	—201	—8
+19	+16	+3	—185	—185	+0
+24	+22	+2	—161	—163	+2
+22	+24	—2	—139	—139	+0
+23	+26	—8	—116	—113	—8
+25	+26	—1	— 91	— 87	—4
+24	+26	—2	— 67	— 61	—6
+23	+22	+1	— 44	— 39	—5
+20	+18	+2	— 24	— 21	—3
+20	+14	+6	— 4	— 7	+3
+ 4	+ 7	—3	+0	+ 0	+0

Plate I.—Bands IV., V., VI., VII., VIII.					
Individual Errors.			Accumulated Errors.		
Observed value of n.	Computed value of n.	Δ	Observed.	Computed.	Δ
+ 7	+ 1	+6	+ 7	+ 1	+6
—11	— 9	—2	— 4	— 8	+4
—16	—18	+2	— 20	— 26	+6
—26	—26	+0	— 47	— 52	+5
—34	—31	—3	— 81	— 83	+2
—35	—33	—2	—116	—116	+0
—30	—32	+2	—147	—148	+1
—27	—28	+1	—174	—176	+2
—21	—21	+0	—195	—196	+1
—13	—11	—2	—208	—207	—1
+ 2	+ 0	+2	—207	—207	+0
+12	+ 9	+3	—195	—198	+3
+23	+18	+5	—172	—180	+8
+26	+27	—1	—146	—153	+7
+29	+31	—2	—118	—122	+4
+31	+33	—2	— 87	— 89	+2
+29	+32	—3	— 58	— 57	—1
+26	+27	—1	— 33	— 30	—3
+22	+20	+2	— 11	— 10	—1
+11	+11	+0	+ 0	+ 1	—1

Finally, we have a severe test in the agreement of the values of n computed for parts of the revolution which were not observed. In order to adapt the equations, for example, to successive ten degrees of revolution, the coefficients of the first equation must be multiplied by $\frac{10}{14.4} = .694$, and those of the second equation must be multiplied by $\frac{10}{18} = .556$. We shall then have: —

$$(1)\ n = -18.5 \sin x + 4.1 \cos x - 0.1 \sin 2x + 0.6 \cos 2x;$$

$$(2)\ n = -16.2 \sin x + 5.4 \cos x - 1.1 \sin 2x + 0.7 \cos 2x.$$

Substituting $x = 0°, 10°, 20°$, &c. in these equations, and comparing the results, we have the following discordances expressed in millionths of an inch: —

Number of millionths,	0	1	2	3	4
Number of cases,	5	7	17	3	4

The average deviation is 19 ten-millionths of an inch, and there are only 7 cases in which the disagreement exceeds 2 millionths of an inch.

(*g*) The relative advantages of the eye-piece micrometer, the filar micrometer, and the screw comparator, for narrow intervals, are nearly equal, as will be seen from the following comparison of the individual values derived by each method of observation, with the normal values found from the equation

$$n = -23.8 \sin x + 5.4 \cos x - 0.1 \sin 2x + 1.0 \cos x,$$

which represents the mean curve for the first band of Plate I.

Number of millionths,		0	1	2	3	4	5	6	7	8	9	10
Number of cases,	Eye-piece micrometer,	7	8	3	5	0	1	0	1	0	0	0
	Filar-micrometer,	4	2	3	5	2	1	5	1	2	0	0
	Merz screw,	4	2	4	2	5	2	2	2	0	1	1

(*h*) It appears from this investigation that it is possible to reduce the errors of a precision-screw for short intervals to about one hundred-thousandth of an inch by applying the corrections derived from the equation which represents the periodic errors. Since the rejection of oil as a lubricant, the errors have been considerably reduced.

(*i*) In a meridian circle having a diameter of 30 inches, one second of arc is equal to .0000727 of an inch. It appears, therefore, from this investigation, that, even if the attached microscopes have the same power as those used in this investigation, the ultimate limit of accuracy in the matter of bisection and reading only, must be at least 0.″05. But the microscopes of the meridian circle of Harvard College Observatory magnify only 51 diameters, while the magnifying powers used in this series of measures were 194, 290, 560, and 870. Moreover, this limit has reference only to repeated readings of the microscopes for the same position of the instrument. It has, therefore, only a *relative* value. When, in addition to the errors of simple pointing and reading, we take into account the accidental and the systematic errors of division in the graduated circles and the outstanding errors always found in measures of large arcs of a circle, the present limit of precision cannot fall much below 0.″2.

Since the completion of this investigation a further opportunity of comparing the results of measures of the same intervals by different observers has occurred. Through the kindness of Professor George F. Barker, of the University of Pennsylvania, I obtained the loan of a

ruled plate from the precision-screw of Mr. L. M. Rutherfurd. This plate is marked " $\frac{68}{360}$ rev." It consists of 11 lines, covering a space as nearly equal to one millimeter as the even notches of the index of the screw will give this value. A transverse line subdivides the vertical lines. The lines are apparently filled with graphite, and they are protected by a coating of transparent varnish.

I first measured the ten spaces of this plate in May, 1878. The plate was then sent to Professor Morley. After its return, and before comparing the results already obtained, it was again measured. In April and May, 1879, still another series of measures was made. The plate was then placed in the hands of Mr. J. R. Edmands, who is a skilful and careful observer with the microscope.

The measures made by Professor Morley and myself were of the separate spaces, and the accumulated errors were found by successive additions. Mr. Edmands made some measures in this way, but he also measured the distance of the successive lines from each of the end lines. The differences between the errors of the adjacent lines were then compared with the direct measures of the spaces, while the sums of the errors of the spaces were compared with the errors of the individual lines. The values given by him were obtained by giving to each determination its proper relative weight.

In accordance with the prearranged plan of observation, each observer remained in ignorance of the results obtained by the other observers until the work of measurement was completed. The following are the values of the corrections required to reduce each space of this particular millimeter to the mean of all the spaces. They are expressed in *millionths of a centimeter*.

INDIVIDUAL ERRORS.

Spaces.	Rogers. May, 1878.	Morley.	Rogers. October and November, 1878.	Rogers. April and May, 1879.	Edmands.	Mean Values.
1	—36	— 8	—37	—16	—14	—22
2	—14	—12	—11	—19	—16	—14
3	— 6	—10	—18	—27	—16	—15
4	— 4	— 1	— 2	+11	+ 2	+ 1
5	— 7	— 1	— 3	— 1	— 3	— 3
6	—28	— 4	—23	— 4	— 3	—12
7	+ 0	— 1	+ 2	— 1	— 1	+ 0
8	+ 8	— 3	+ 4	+ 2	— 3	+ 2
9	+35	+ 3	+33	+13	+10	+19
10	+52	+35	+55	+42	+44	+46

ACCUMULATED ERRORS.

Spaces.	Rogers. May, 1878.	Morley.	Rogers. October and November, 1878.	Rogers. April and May, 1879.	Edmands.	Mean Values.
1	—36	— 8	—37	—16	—14	—22
2	—50	—20	—48	—35	—30	—37
3	—56	—30	—66	—62	—46	—51
4	—60	—31	—68	—51	—44	—51
5	—67	—32	—71	—52	—47	—54
6	—95	—36	—94	—56	—50	—66
7	—95	—37	—92	—57	—51	—66
8	—87	—40	—88	—55	—54	—65
9	—52	—37	—55	—42	—44	—46
10	— 0	— 2	— 0	— 0	— 0	— 0

It is somewhat doubtful whether the mean values given, represent the actual errors of the spaces. There are some indications that a shrinkage of the film of varnish has occurred since it was first applied, and this action may have produced some effect upon the graphite with which the lines are filled. Although graphite is an impalpable powder, I have seen many instances in which it has been lifted in mass from the filled lines and thrown a distance as great as one thousandth of an inch without breaking the continuity of the particles. This action seems to take place only when the lines and the filling are protected by a thin cover-glass, closely cemented to the slip on which the lines are ruled. Sometimes an explosion seems to take place, scattering the graphite in all directions, leaving it in curves having nearly a uniform shape. I have never been fortunate in seeing this action, but in the case of one ruled plate an actual observation limits the time within which the explosion must have occurred to about ten days. In this case the lines remained perfect for about four months after

they were ruled and filled, but between the 1st and the 10th of April of the present year nearly one half of the powder was completely removed from the lines.

It is possible also, that some of the discordances are due to the fact that the measures were not all made along the same horizontal line. My earlier measures were made along a line just above the transverse line, while the later ones were made along a line a little below the transverse line. My observations of April and May of the present year, and those made by Mr. Edmands, ought to be comparable, since they were made at nearly the same time and along the same line. The greatest disagreement is in the third space; and that the discordance is not an accidental one is shown by the fact that *all* my observations agree in giving —27, while *all* of his agree in giving —16. But, admitting that the discordances are all due to errors of observation, it will be seen that the average deviation from the mean is only 6 millionths of a centimeter.

XIV.

PRELIMINARY REPORT ON THE ECHINI OF THE EXPLORING EXPEDITION OF H. M. S. "CHALLENGER," SIR C. WYVILLE THOMSON CHIEF OF CIVILIAN STAFF.

By Alexander Agassiz.

[PUBLISHED BY PERMISSION OF THE LORDS OF THE ADMIRALTY.]

Presented May 14, 1879.

It was not my intention to publish a preliminary notice of the Echini collected by the *Challenger*. I hoped to be able to issue the descriptions of the species with my final report on the group. I am compelled, however, for the sake of retaining for the material of the *Challenger* expedition the priority of discovery, to notice briefly the magnificent collection of Sea-urchins intrusted to my care by Sir Wyville Thomson. The two expeditions of the U. S. Coast Survey steamer *Blake*, in which I was allowed, by the Superintendent of the Coast Survey, to carry on very extensive dredging operations in the Straits of Florida, the Gulf of Mexico, and the eastern part of the Caribbean Sea, have brought together extensive deep-sea collections, second only to those of the *Challenger*. In most of the groups, judging from my recollection of the *Challenger* collections when I had the privilege of examining them at Edinburgh, I should say that the collections made on the *Blake* not only include duplicates of the species of the *Challenger*, but numerous representatives of the principal families collected by that expedition. I wish, of course, as far as possible, to guard against any anticipation of the results to be drawn from the older collections of the *Challenger*. With the exception of certain Pourtalesiæ, of which I obtained only a few perfect specimens on the *Blake*, (although numerous fragments were constantly brought up by the trawl from depths of between 1,000 and 2,000 fathoms,) the Echini collected by the *Blake* represent some of the most interesting forms obtained by the *Challenger*, and often complement more or less imperfect *Challenger*

material. I shall, of course, not hesitate, in my final report on the *Challenger* Echini, to avail myself of this additional material. It is quite important, both from a systematic point of view and for determining more accurately the bathymetrical range of the greater number of the *Challenger* Echini, showing, as it does, that many species thus far considered as deep-sea species approach very nearly the hundred-fathom line.

Among the CIDARIDÆ, in addition to the new species of genera well known before, the most interesting form is a fine species of *Porocidaris*, n. sp. (*P. elegans*, A. Ag.). Large and valuable material was also collected for the study of *Goniocidaris canaliculata*, A. Ag., including its earliest stages and many varieties, as well as a most extensive series of *Goniocidaris tubaria*, showing a range in the variation of the spines unknown in any other species of the genus.

A new species of *Salenia* (*S. hastigera*, A. Ag.), the third now known, was also discovered. Of this many specimens were collected.

Among the ARBACIADÆ I note a species of *Porocidaris* (*P. prionigera*, A. Ag.), and a large series of *Cœlopleurus Maillardi*. This has enabled me to make a careful study of this interesting genus.

In the family of DIADEMATIDÆ, a new genus allied to *Astropyga*, *Micropyga* (*M. tuberculatum*, A. Ag.), and two species of a genus closely allied to *Trichodiadema*, *Aspidodiadema* (*A. tonsum*, A. Ag., and *A. microtuberculatum*, A. Ag.), have been collected.

Among the ECHINOTHURIÆ a number of new species were dredged, both of *Asthenosoma* and of *Phormosoma*, in addition to the species already described by Sir Wyville Thomson in the "Echini of the Porcupine," the "Depths of the Sea," and the "Voyage of the Challenger." They are *A. pellucida*, A. Ag., *A. Grubei*, A. Ag., *A. tessellata*, A. Ag., *A. coriacea*, A. Ag., *P. luculenta*, A. Ag., and *P. tenuis*, A. Ag. Several small specimens of these genera were also collected, but it will be impossible to do more than refer them temporarily to existing species, as the material is hardly sufficient for exact determination. I hope, however, by making use of the many young Echinothuriæ collected by the *Blake* for comparison, to determine them more satisfactorily.

Among the ECHINOMETRADÆ nothing of importance was collected.

Among the TEMNOPLEURIDÆ excellent series of the species of *Salmacis* and of *Temnopleurus* were obtained; a new species of *Trigonocidaris* (*T. monolini*, A. Ag.), a *Cottaldia* (*C. Forbesiana*, A. Ag.), hitherto only known from the Chalk, and an exquisite genus, *Prionechinus* (*P. sagittiger*, A. Ag.), allied to *Salmacis* and *Podocidaris*.

The most interesting feature of the ECHINIDÆ proper was the occurrence of several northern forms, *E. acutus*, *E. elegans*, and *E. norvegicus*, in deep water in the tropics.

Not a single new species of Clypeastroid was found, and the number of specimens even was quite small. They do not play any important part in shaping the character of the fauna of deep water, and are, perhaps, the most strictly littoral group of Echini, indicative, at least in the present epoch, of comparatively shallow water, inside of the hundred-fathom line, and probably giving us a good guide as to the depth of the sea and the nature of the bottom of the cretaceous and tertiary shores, where they occur in such large numbers.

A recent species of *Catopygus* (*C. recens*, A. Ag.) is interesting as adding another of the cretaceous forms to those still found living.

By far the most interesting group of Echini collected by the *Challenger* is the group of POURTALESIÆ. They were known before only from a couple of genera and a few species collected in the expeditions of the Coast Survey and by the *Porcupine*. The old material was very limited; the present material is, in some cases, abundant, and has enabled me to study the affinities of this remarkable group; passing on the one side from *Pourtalesia* proper to such groups as *Aerope*, W. Th., and *Aceste*, W. Th., with the gigantic suckers of their petaloid ambulacra, and on the other, through genera with short anal snouts, as *Cionobrissus*, A. Ag., and *Spatagocystis*, A. Ag., to *Echinocrepis*, A. Ag., and *Calymne*, W. Th., in which the resemblance to *Infulaster* gradually fades, and such genera as *Urechinus*, A. Ag., and *Genicopatagus*, A. Ag., appear, reminding us of *Holaster*, while *Cystechinus* recalls *Ananchytes* proper with many features of *Micraster*.

Of *Pourtalesia*, no less than six species are found in the collection, five of which were not among the earlier deep-sea POURTALESIÆ. (They are *P. hispida*, A. Ag., *P. laguncula*, A. Ag., *P. rosea*, A. Ag., *P. ceratopyga*, A. Ag., and *P. carinata*, A. Ag.)

Of *Cionobrissus* (*C. revinctus*, A. Ag.), *Spatagocystis* (*S. Challengeri*, A. Ag.), *Echinocrepis* (*E. cuneata*, A. Ag.), *Genicopatagus* (*G. affinis*, A. Ag.), and *Urechinus* (*U. naresianus*, A. Ag.), only one species of each genus was brought home. An additional species of *Homolampas* (*H. fulva*) shows that the species of this genus grow to a very considerable size.

A number of specimens of *Paleopneustes* (*P. Murrayi*, A. Ag.) were collected near Kagosima, which it may be necessary to place in a separate sub-genus. There are peculiarities in the marginal fascioles and their development, the value of which can only be determined by

comparison with a more extensive series of younger stages. Fortunately there are quite a number of the young of Paleopneustes in the *Blake* collections.

In *Cystechinus* there are three species: *C. Wyvillii*, A. Ag., and *C. clypeatus*, A. Ag., the test of which is quite stout, while in *C. vesica*, A. Ag., the test is reduced to a mere film, so that even in alcohol the shape of this Sea-urchin reminds one of the crown of an old felt hat which has seen its best days.

The test of all the POURTALESIÆ is quite delicate, the amount of limestone being, at the great depths where they occur, reduced to a minimum, and yet at the greatest depth at which these delicate Echini are found they are associated with Ophiurans which are by no means wanting in limestone.

Among the EUSPATANGINA, *Spatangus purpureus* occurs in the tropics at a depth of 400 fathoms, and *Echinocardium australe* is found littoral and at the great depth of 2,675 fathoms. With the exception of a new Spatangoid allied to Maretia, *Argopatagus vitreus*, A. Ag., nothing demanding special notice was obtained.

Among the BRISSINA two species of *Hemiaster* allied to the cretaceous *H. prunella* were obtained (*H. gibbosus*, A. Ag., and *H. zonatus*, A. Ag.); also an extensive series of *Hemiaster cavernosus*, A. Ag., plainly showing that the several species thus far recognized, *H. antarctica*, *H. Philippii*, and *H. cordatus*, are only the different stages of growth of the males and females of Philippi's original *T. cavernosus*. In addition to *Periaster limicola*, A. Ag., which is inadvertently described from the Echini of the first *Blake* expedition, a new species of *Rhinobrissus* (*R. hemiasteroides*, A. Ag.) and two new species of *Schizaster* (*S. claudicans*, A. Ag., and *S. japonicus*, A. Ag.) close the list of this extraordinary collection.

I can give no better idea of the value of this collection than by stating that there are in the accompanying list not less than forty-four new species. At the time the "Revision of the Echini" was published, which included the large number of unknown forms collected by Mr. Pourtalès in the Straits of Florida, there were not many more than two hundred species of Echini known, and since that time less than fifty species have been added to the list.

With regard to the geographical distribution of the deep-water species, the North Atlantic is in striking contrast with the North Pacific and the Southern Ocean. The Pacific is remarkable for its numerous species of littoral Cidaridæ, which are few in number in the Atlantic; of Dorocidaris and of Porocidaris, there is one Atlantic

and one Pacific species of each. Goniocidaris is a Pacific genus, with the exception of *Goniocidaris canaliculata*, which is the characteristic species of the great ocean belt uniting the extreme Southern Atlantic and the Southern Indian Ocean. Salenia, Podocidaris, Cœlopleurus, and Aspidodiadema each have one Atlantic and one Pacific species. The Northern Pacific, however, is characterized by the greater number of Echinothuriæ; the Atlantic collection of the *Challenger* containing only two species of the family, while there are no less than ten or eleven in the Pacific. Trigonocidaris has an Atlantic and a Pacific species. Several of the Echini proper, well known from the Northern European seas, extend far into the South Atlantic, as *E. acutus*, *E. elegans*, and *E. norvegicus*, the latter being even found in the Pacific, while the representatives of their species found along the southern extremity of South America, *E. magellanicus* and *E. margaritaceus*, extend far into the Southern Indian Ocean towards the Kerguelen and Heard Islands.

Of the Clypeastroids, *Echinocyamus pusillus* appears to be the only species having a wide geographical range and a great bathymetrical distribution; it extends from the Northern European seas to the South Atlantic.

The new species of Catopygus is a tropical Pacific species, as well as Palæotropus.

The species of Pourtalesia proper thus far known were, of course, Atlantic. The *Challenger* discovered two species in the Pacific; but by far the greater number of the species of this family were found in the Southern Indian Ocean in the track from the Cape of Good Hope to the Kerguelen Islands, and thence to Australia: three species of *Pourtalesia* proper (*P. hispida*, *P. phyale*, *P. carinata*), *Spatagocystis Challengeri*, *Echinocrepis cuneata*, *Genicopatagus affinis*, and *Urechinus nauresianus*, as well as the three species of *Cystechinus* (*C. vesica*, *C. clypeatus*, and *C. Wyvillii*). Of these one extends into the South Atlantic, *C. clypeatus*, the other into the South Pacific.

Aceste and Aerope are Pacific genera, and Calymne is an Atlantic genus. Homolampas and Paleopneustes each have an Atlantic and a Pacific species.

Of the Spatangina proper, nearly all are littoral Pacific species, with the exception of *Argopatagus vitreus* and the deep-water South Pacific *Echinocardium australe*. *E. flavescens* is also found reaching far into the Southern Indian Ocean. Of the northern species of Spatangus, *S. purpureus* extends well south in the North Atlantic and *S. Raschi* reaches as far as the Cape of Good Hope.

The most common species of the Brissina is *Hemiaster cavernosus*, which occurs in large number in moderately deep water at the Kerguelen Islands, the southern extremity of South America. *Hemiaster gibbosus* is a Pacific species, of which *H. zonatus* is the Atlantic representative. The northern *Brissopsis lyrifera* and *Schizaster fragilis* are found in the South Indian Ocean. The Pacific Schizasteridæ were *S. claudicans*, *S. ventricosus*, and *S. japonicus*, while *S. Philippii* ranged from the southern extremity of South America through the South Pacific to the Southern Indian Ocean.

The following are the main points of the bathymetrical distribution of the Echini of the *Challenger* expedition.

Among the CIDARIDÆ, *Cidaris* proper, *Phyllacanthus*, *Stephanocidaris*, and *Goniocidaris* are littoral, and extend but little beyond the 100-fathom line; though *G. canaliculata* has been found to 1,700 fathoms.

Dorocidaris extends to a depth of 600 fathoms, while *Porocidaris* was not found in less than 400 fathoms, and extended to a depth of nearly 2,000 fathoms.

The SALENIDÆ extend from the 100-fathom line to 1,850 fathoms.

In the ARBACIADÆ the species of *Arbacia* proper are littoral, and are found to a depth of 150 fathoms; from 80 to somewhat over 100 fathoms extends *Cœlopleurus*, while the species of *Podocidaris* are the deep-water forms of this family, with a range of from 400 fathoms to nearly 1,100.

Among the DIADEMETIDÆ, *Diadema* and *Echinothrix* are strictly littoral, while *Astropyga* and the new genus *Micropyga*, closely allied to it, occur quite frequently from 75 fathoms to 250 fathoms, and even occasionally to a depth of 600. The genus *Aspidodiadema* commences at a depth of 100 fathoms, takes a greater development at about 600 to 700 fathoms, and has been found at a depth of over 2,200 fathoms. This genus, with the species of *Asthenosoma* and *Phormosoma*, are the deep-water types of the family, and of the ECHINOTHURIÆ, for although one of the species of *Asthenosoma* occurs in ten fathoms, the larger number of the species of the genus are not found in less than 100 fathoms, the greater number occurring in 200 to 300 fathoms and extending to 2,600 fathoms. The species of *Phormosoma* collected by the *Challenger* are found mainly in from 250 to 1,000 fathoms, being still common from 1,000 to 2,000 fathoms, and found as deep as 2,750 fathoms.

The ECHINOMETRADÆ are all shallow-water species, no species extending beyond the 100-fathom line.

Of the TEMNOPLEURIDÆ, *Prionechinus*, *Cottaldia*, and *Trigonocidaris* alone are deep-water species. *Cottaldia* occurring about 300 fathoms, *Trigonocidaris* from 500 to 1,000 fathoms, while *Prionechinus* ranges from 700 to nearly 1,100 fathoms. With the exception of *Temnopleurus Regnaudi*, A. Ag., which was found by the *Challenger* down to a depth of 275 fathoms, none of the other species of *Temnopleurus*, nor of those of *Microcyphus*, *Salmacis*, *Mespilia*, *Amblypneustes*, or *Holopneustes*, reached beyond the 100-fathom line, and by far the greater number of the species do not extend beyond the 40-fathom line.

Among the TRIPLECHINIDÆ, *Toxopneustes*, *Hipponoë*, and *Evechinus* are littoral.

In the genus *Echinus* proper, while a few of the species appear to be strictly littoral, we find several having a most extended bathymetrical range from strictly littoral to 1,600 fathoms, several northern species appearing in deep water in the tropics.

Among the CLYPEASTROIDS, with the exception of the FIBULARINA and of one species of *Peronella*, all the genera are littoral, *Echinanthus* alone extending to a depth of 120 fathoms, while no species of *Mellita*, *Encope*, *Echinodiscus*, *Astriclypeus*, *Laganum*, or *Clypeaster* was found beyond 70 fathoms.

The small number of Clypeastroids dredged by the "*Challenger*" is very striking, plainly showing that of this group the ECHINANTHIDÆ are eminently littoral, though in the FIBULARINA the species of *Echinocyamus* extend to 400 fathoms and those of *Fibularia* to 950 fathoms. One species of Peronella extended to 300 fathoms.

My own experience while dredging in the *Blake* corresponds with this. Although working in the region where the littoral species of the group are very numerous, we collected but few species of *Scutellidæ* or of *Echinanthidæ*, even while dredging near the 100-fathom line. The same is true of the former expeditions sent out by the Coast Survey.

Of the NUCLEOLIDÆ, the genera *Echinolampus* and *Catopygus* were limited to the region of 120 fathoms.

We now come to a strictly deep-water family, the POURTALESIÆ, as we may for the present call the group to which *Pourtalesia*, *Palæotropus*, *Aerope*, *Aceste*, *Calymne*, and the like, belong. No species of the group has as yet been found in less than 375 fathoms; at this depth they occur rarely. They have been found more commonly at from 600 to 700 fathoms; they seem to take their greatest development at from 1,000 to 2,000 fathoms, and they are not uncommon

down to the depth of 2,300 to 2,900 fathoms; the genera *Palæotropus* and *Cionobrissus* being limited to a less depth than 1,000 fathoms, while *Aerope*, *Calymne*, and two or three species of *Pourtalesia*, are found within these limits, but also extend to the greatest depth at which any Echini have been found, viz. 2,900 fathoms.

The genera *Spatagocystis*, *Echinocrepis*, *Genicopatagus*, *Urechinus*, and *Cystechinus*, range mainly between 1,300 and 2,000 fathoms, one of the species of the latter genus extending to 2,225 fathoms, while *Aceste* has only been found in 2,600 fathoms thus far.

Paleopneustes occurs in the neighborhood of 300 to 400 fathoms, and *Homolampas* is found at a depth of 400 fathoms and over.

Among the SPATANGINA, the northern *Spatangus purpureus* is found in the tropics at a depth of 450 fathoms. *Eupatagus*, *Lovenia*, *Breynia*, and *Maretia planulata* are strictly littoral, not extending beyond a depth of 28 fathoms. *Maretia alta* has been found to extend to a depth of 800 fathoms; and the species of *Echinocardium*, like those of *Brissopsis*, although littoral, yet extend to great depth, one species, *Echinocardium flavescens*, to 150 fathoms, while *E. australe* has come up from no less than 2,675 fathoms. The only species of the genus *Argopatagus* was found at a depth of 800 fathoms.

Among the BRISSINA, *Rhinobrissus*, *Periaster*, *Metalia*, and some species of *Schizaster*, are either littoral or do not extend to the 100-fathom line, or but little beyond it. The species of *Schizaster*, however, reach a considerable depth; in one case 1,375 fathoms, in another 800, and in a third 345 fathoms. The species of *Hemiaster*, also, greatly vary in their bathymetrical range, the two species most closely allied to the cretaceous *Hemiaster prunella* extending from 340 to 800 fathoms, while *Hemiaster cavernosus* ranges from 15 to 400 fathoms. In *Brissopsis lyrifera* the bathymetrical range extends from 15 to 1,100 fathoms. The Mediterranean *Brissus unicolor* extends to a depth of 450 fathoms.

Dorocidaris bracteata, A. Ag., nov. sp.

This species is closely allied to *Dorocidaris papillata*. It is characterized by the small papillæ covering the abactinal area, the small size of the mammary boss of the primary tubercles, and the greater distance between the primary tubercles compared with the Atlantic species, *D. papillata*. The primary radioles are fluted, with a more or less serrated edge. The ambulacral system is also relatively much

narrower in this species than in the Atlantic species. — Amboyna, 100 fathoms, 15 fathoms.*

Porocidaris elegans, A. Ag., nov. sp.

The principal differences between this species and *P. purpurata* consist in the shape of the primary radioles. These are more uniform in shape, some of them three times in length the diameter of the test, with a comparatively short collar above the milled ring; the length of this collar is often half the length of the spine in *P. purpurata*. The abactinal system of this species is remarkable for the great size of the genital openings, placed entirely within the genital plates, and not extending, as in *P. purpurata*, into the apical plates of the interambulacral area. — Station 214, 500 fathoms; Station 164, off New South Wales, 950 fathoms, 410 fathoms.

Goniocidaris florigera, A. Ag., nov. sp.

In no species of the genus is there so great a difference between the spines of different parts of the test, or of different individuals, varying from short cupuliform or even spines terminating with radiating spokes, to long cylindrical radioles thickly covered with spines irregularly arranged, or to gradually tapering spines with delicate serrations and spines quite regularly placed. The ornamentation of the test is limited to small, deep pits at the angles in the median line of the interambulacral plates, with a sharp bare line indicating the sutures also at the junction of coronal plates with the poriferous zone. The lower part of the ambulacral plates is covered by minute granules, leaving the upper part of the plate bare; median ambulacral space wider than poriferous zone, coronal plates high, mammary boss small, scrobicular area deep, not confluent, completely separated by intervening secondary tubercles. Ocular plates heart-shaped, genital plates hexagonal, both covered by coarse granulation; papillæ sharp and slender; ten large anal plates, with smaller ones in centre; genital opening large, placed towards the centre of the plate. — Ki Islands, 129 fathoms; Station 204, 100 fathoms.

Salenia hastigera, A. Ag., nov. sp.

Differs from *Salenia varispina* by the closer and uniform granulation covering the abactinal system and the relatively smaller anal

* Only the principal localities are given, showing the bathymetrical and geographical range.

system. The spines are much longer also, nearly four times the diameter of test, varying but little in shape; they taper gradually and are covered from tip to base with numerous small spines closely packed in regular rings round the shaft. The number of primary plates is smaller both in the ambulacral and interambulacral areas, the three largest tubercles of the interambulacral area occupying in this species the same relative space of the test occupied by five in *Salenia varispina*. The large ambulacral tubercles of the actinal region so characteristic of the latter species are not found in *S. hastigera*, the actinal tubercles are but slightly larger than the other ambulacral tubercles. — Station 195, 1,425 fathoms; Station 170, 630 fathoms; Station 335, 1,425 fathoms; off Cebu, 100 fathoms.

Podocidaris prionigera, A. Ag.

This species is readily distinguished from its West Indian congener by the greater length of the spines; they are more regularly tapering, flattened, with very prominent serrations of the two edges. — Station 218, 1,070 fathoms; Station 205, 1,050 fathoms.

Aspidodiadema, A. Ag., nov. gen.

This genus is intermediate between the Cidaridæ proper and the Diadematidæ. It has, like the latter, a thin test with the spines characteristic of that family. It has, like Centrostephanus, buccal plates. But the primary tubercles are few in number, as in the Cidaridæ, occupying with the scrobicular area and accompanying secondary spines nearly the whole of the interambulacral plate. The most characteristic feature of the genus is the ambulacral system. The plates, of a nearly uniform size, are small, forming, as in Cidaridæ, a narrow ambulacral system. The abactinal system consists of a narrow ring of ocular and genital plates placed side by side surrounding a large anal system. Two species were collected by the *Challenger*.

Aspidodiadema tonsum, A. Ag., nov. sp., in which the anal system is protected by five large plates, occupying the greater part of the space enclosed by the genital and ocular ring, and in which the actinal ambulacral tubercles form a double row of tubercles much larger than those of the abactinal region of the ambulacral space, which extends nearly to the middle of the test. — Station 170, Kermadec Islands, 630 fathoms; off Cebu, 100 fathoms; Station 122, 356 fathoms; off Macio, 1,700 fathoms.

The second species is *Aspidodiadema microtuberculatum*, A. Ag., nov. sp. It can be at once distinguished from its congener by the

larger number of plates protecting the anal and actinal systems, and also by the uniform size of the tubercles of the median ambulacral space along its whole length. The primary spines of this species are stouter and comparatively shorter than those of *A. tonsum*, some of which are nearly three times the length of the test; the number of primary plates is less in this species than in the preceding one. — Station 298, 2,225 fathoms; Station 134, 2,025 fathoms.

Micropyga, A. Ag., nov. gen.

Allied to Astropyga, it has, like it, a flat test, short spines, but a more compact abactinal system, a small actinostome with deep indentations for the passage of the gills, and primary tuberculation extending both in ambulacral and interambulacral areas to the abactinal system.

Micropyga tuberculata, A. Ag., nov. sp.

The spines of the abactinal surface are pointed, while on the actinal surface, where the primary tubercles form a closely-packed pavement both in the ambulacral and interambulacral areas, the primary spines are club-shaped, and the secondary spines alone are pointed. — Off Cebu, 100 fathoms.

Asthenosoma pellucida, A. Ag., nov. sp.

This species, judging from alcoholic specimens, was probably of light green or yellowish color; it is readily distinguished from *A. hystrix*, its nearest allied species, by the narrow ambulacral zone and the very regular arrangement of the secondary tubercles in a horizontal row occupying the centre of each primary plate. — Off Cebu, 100 fathoms; Station 192, 129 fathoms.

Asthenosoma Grubei, A. Ag., nov. sp.

This species is closely allied to *Asthenosema varium* of Grube, and these two species may perhaps properly form a separate section of the genus, while such species as *A. pellucida*, *A. hystrix*, and *A. fenestrata* would form a second subgenus. The material collected by the *Challenger* is scarcely sufficient to determine this. From the large number of specimens of the genus collected by the *Blake*, I hope to be able to determine, before the final report is published, the range of variation in one or two of the species. The test of this species is quite tough, the primary plates extremely narrow in both areas, well covered by primary tubercles arranged in one row; these are larger on the actinal surface and separated by few smaller secondary tubercles

rather irregularly placed. On the actinal membrane the tubercles of both areas are identical in size, forming regular concentric rings broken by the bare spaces in the median areas round the actinostome. The spines of the actinal surface are more or less trumpet-shaped at the extremity, with well-worn tips; those of the abactinal region are pointed and generally covered by a loose muscular sheath extending beyond the end of the spine, forming a series of swellings, from four to six, around the sharp cylindrical spine which it encloses. — Zamboanga, 10 fathoms.

Asthenosoma coriacea, A. Ag., nov. sp.

Distinguished from the preceding by its broader primary plates and by having similar spines on both the actinal and abactinal surfaces. The primary tubercles are few in number, limited mainly to the proximity of the edge of the test, both on the actinal and abactinal sides. One principal row extends to the abactinal area on the edge of the interambulacral plates of the abactinal side, and one on the actinal side. The remainder of the interambulacral plates are closely covered by small secondary tubercles or miliaries. In the ambulacral area the large primary tubercles extend only over a few plates on each side of the middle of the test. — Station 204, 100 fathoms; Station 173, 310 fathoms; Tongatabu; Station 299, 2,160 fathoms.

Asthenosoma tessellata, A. Ag., nov. sp.

The specimen on which this species is established may prove to be only a younger stage of the preceding. It presents, however, such striking features in the extremely regular arrangement of its plates, both on the actinal and abactinal sides, and their uniform size both in the ambulacral and interambulacral areas, that for the present it may be convenient to distinguish this species from *A. coriacea* until we know something more of the changes this group of Echini undergo during growth.

The same remarks apply to a number of small Asthenosomæ and Phormosomæ which, unfortunately, coming from many different localities, I am unable, on account of the great differences they show from the fully-grown forms, to associate them at present with any of the species here described. — Station 200, 250 fathoms.

Phormosoma luculenta, A. Ag., nov. sp.

This species is readily distinguished from the others of the genus by the greater solidity of the test, its pinkish or violet color seen

from the abactinal side, and the few long, large, dark violet primary spines of this surface, with similarly colored short, fine secondary and miliary spines standing out in bold contrast to the light test, and by the large size of the anal system and of the genital openings on the actinal side. The primary tubercles of the actinal side carry large spines tipped with white cup-shaped appendages, performing for this group the same functions as a similar tip on the spines of the actinal side of the Arbaciadæ. The secondary and miliary spines similar to those of the abactinal side. One specimen in the collection differs from the majority of the others in having the test and spine of a uniform yellowish-pink color. Station 200, 255 fathoms; Station 205, 1,050 fathoms; Station 332, 245 fathoms.

Phormosoma tenuis, A. Ag., nov. sp.

Closely allied to *Phormosoma uranus*, W. Th., from which it differs mainly in having larger and more numerous primary tubercles, especially on the actinal side, while on the abactinal side the small number of miliaries occurring in this species give it a very different facies. The coronal plates are more numerous in *P. uranus* than in specimens of the same size of this species, and the abactinal system is also proportionally smaller in *P. tenuis*, and the anal system made up of larger plates. — Station 274, 2,750 fathoms; Station 237, 1,875 fathoms.

Prionechinus sagittiger, A. Ag., nov. gen. & sp.

The apical system of this genus is similar to that of Salmacidæ. Single row of plates of pores on each side of median ambulacral line. Actinal membrane covered by plates. Spines serrated, somewhat flattened, radically different from those of any other genus of Triplechinidæ. As is well known, the serrations of the spines of young Echini proper disappear with age, and it is only among the Cidaridæ, Salenidæ, and the like, that we find spines greatly differing in allied genera or species, the spines of the Echinidæ proper being remarkable for their uniformity. Unfortunately only indifferently preserved specimens of this interesting genus were collected, and they are probably not fully grown, as the large anal system is still covered by a few large plates, as in all young Echini. Genital plates of uniform size; ocular plates notched in apex, excluded from anal system. — Station 164, 950 fathoms; Station 218, 1,070 fathoms.

Cottaldia Forbesiana, A. Ag., nov. sp.

There is only a single specimen of this interesting species (probably not full grown). It is closely allied to the tertiary *Psammechinus monilis*; pores are arranged in simple vertical rows, much as in *Temnechinus*. The spines similar to those of Salmacidæ; large abactinal system of *Temnopleurus*, without, however, any trace of the indentations and pits of the Salmacidæ and Temnopleuridæ. Actinostome sunken, actinal membrane covered with ten large plates, spine white or a yellowish orange, primary tubercles of the same size in both areas, forming a very marked vertical row in the ambulacral area; secondaries forming indistinct horizontal rows near the ambitus, genital opening small, sharply cut; genital plates crowded with secondaries, anal system covered by few plates. — Station 173, 315 fathoms.

Trigonocidaris monolini, A. Ag., nov. sp.

This species is readily distinguished from *T. albida* by the structure of its actinal membrane and the striking ornamentation of the genital ring, and the relatively smaller number of primary coronal plates and coarser pitted reticulation, both in the ambulacral and interambulacral areas. The ten buccal plates occupy nearly the whole of the distal edge of the actinal ring, while in *T. albida* they are small and the actinal membrane is crowded by imbricating plates. A prominent ridge extends round the edge of the ocular plates and across the adjoining genital plates, forming a pentagon with rounded angles round the anal system; two or three prominent secondary tubercles are placed in the middle of the genital plates. No similar ornamentation in found in *T. albida.* — Station 170, 520 fathoms.

Echinus horridus, A. Ag., nov. sp.

Fragments and imperfect specimens of a large conical Echinus were collected in the Straits of Magellan which cannot be referred to any of the species already known from that locality. It seems to be readily characterized by its narrow poriferous zone. One principal row of primary tubercles in the interambulacral space, with secondaries in irregular diverging lines from it; the spines are remarkable for their length, even comparatively much longer than in some specimens of *E. acutus;* abactinal system very compact; large genital plates, small ocular plates. Actinostome small, not as large as abactinal system; color of test reddish brown when dry, spines darker color. — Off Tom Bay; Station 308, 175 fathoms.

Catopygus recens, A. Ag., nov. sp.

Only denuded tests of this species were collected. Apex anterior and corresponding with apical system. Prominent rounded keel at extremity of anal groove, sloping towards the actinostome, three genital pores, abactinal system indistinct, odd anterior and anterior pair of ambulacra of equal length, longer than posterior ones; tubercles forming uniform granulation over the test, phyllodes and bourrelets well marked. Test gibbous in median odd posterior interambulacral space between apical system and anal opening, also in the centre of the plates of the lateral posterior interambulacra, the swelling of this portion of the test becoming more prominent on the actinal side; actinostome sunken, upper edge of anal opening flush with the test, the posterior edge at the bottom of the anal groove. Ambulacral plates of nearly uniform size along sides of the test, becoming gradually narrower towards actinostome. — Station 192, 129 fathoms.

Palæotropus Loveni, A. Ag., nov. sp.

Differs from the West Indian *P. Josephinæ* in being more elongate, in having its greatest breadth near the posterior extremity; apical system, on the contrary, nearer the anterior extremity. It has also a larger subanal fasciole; the anus is placed on the upper plane of the truncated posterior end; its greatest diameter is horizontal, the posterior part of the actinal plastron forms a rounded keel. — Station 210, 375 fathoms.

Pourtalesia hispida, A. Ag., nov. sp.

The species of Pourtalesia proper are readily separated into two groups from the character of the test, the one containing such rectangular forms, or more or less bottle-shaped forms, as two of the species of Pourtalesia previously known (*P. miranda*, *P. phiale*), with the additional species discovered by the *Challenger* (*P. laguncula*, *P. hispida*), and such forms as *P. ceratopyga* and *P. rosea*, which are more or less triangular in outline when seen from above, their broad anterior extremity sloping gradually towards the anal end, while the rectangular forms, such as *P. hispida*, *P. carinata*, *P. Jeffreysi*, are intermediate between the two groups, having something of the rounded test of the former group, and the flattened actinal side with the more solid test of the last. The present species, *P. hispida*, differs from its nearest ally, *P. Jeffreysi*, in having a shorter anal snout, a more flattened actinal surface, a smaller actinal plastron, and a smaller number

of larger primary tubercles arranged in horizontal rows across the primary plates. Its outline is more rectangular anteriorly, and more nearly vertically truncated. — Station 147, 1,600 fathoms; Station 156, 1,975 fathoms.

Pourtalesia laguncula, A. Ag., nov. sp.

This is very closely allied to *P. miranda;* it is, however, more bottle-shaped, comparatively broader at the anterior extremity, shorter, with a wide anal snout and a more vertically truncated anterior extremity; shorter actinal plastron, with broad fasciole round the anal snout. This fasciole I did not detect in *P. miranda*, and as the unique specimen is at present in the hands of Professor Lovén I am unable to give its position in that species. — Station 191, 800 fathoms; Station 168, 1,100 fathoms; Station 232, 344 fathoms; Station, 244, 2,900 fathoms.

Pourtalesia carinata, A. Ag., nov. sp.

This is a large species with a comparatively stout test, quite gibbous, apex posterior, with its greatest breadth near the posterior extremity; largest primary spines on median interambulacral line of abactinal side of test in the anterior and in the odd interambulacra; rest of test quite thickly covered with small secondary spines, increasing in size towards the ambitus; on the actinal side the plastron carries still larger primary spines closely packed on the ridge of the actinal keel. — Station 299, 2,160 fathoms; Station 157, 1,950 fathoms.

Pourtalesia ceratopyga, A. Ag., nov. sp.

Test seen from above, triangular, with rounded apex formed by anal snout and base with rounded corners and re-entering centre, as well as re-entering sides. Seen in profile, the outline is rectangular, with the anal snout projecting from the posterior extremity like a knob. The actinal side is nearly flat, the abactinal outline somewhat rounded posteriorly (apex posterior), while abactinal system is placed nearer the anterior extremity, which also rounds off gradually. Seen endwise, the outline is triangular, with rounded corners; actinal groove less pronounced than in the species of the *P. miranda* type. The test is thickly covered by tubercles of nearly uniform size, irregularly arranged, carrying short slender spines; they are larger and carry longer spines along the abactinal keel and on the sides of the actinal groove. The color of the test, which is quite solid, is deep violet. — Station 298, 2,225 fathoms.

Pourtalesia rosea, A. Ag., nov. sp.

Fragments only of this species were collected. It is, however, well characterized by the peculiar shape of the anal snout, which is laterally compressed, truncated posteriorly. From the few fragments of the test found they must belong to a large species closely allied to *P. ceratopyga*. — Station 272, 2,600 fathoms.

Cionobrissus revinctus, A. Ag., nov. gen. & sp.

This genus is interesting, pointing as it does to the affinity of the Pourtalesiæ and Brissina. It resembles Brissopsis somewhat, has like it a peripetalous fasciole and petaloid ambulacra, and also possesses a well-marked subanal fasciole surrounding what corresponds to a rudimentary anal snout, somewhat like the beak of Echinocardium. The large tubercles within the peripetalous fasciole recall Macropneustes, and the groove at the end of which is placed the actinostome, with the rounded actinal surface with its keeled actinal plastron, remind us somewhat of the Pourtalesiæ. The spines of the test are pretty uniform in size, with the exception of the larger ones within the peripetalous fascioles. — Station 191, 800 fathoms.

Echinocrepis cuneata, A. Ag., nov. gen. & sp.

This genus has, like Pourtalesia, a deeply-sunken actinal groove and simple ambulacral pores piercing the test. It has, like the species of the group to which *P. ceratopyga* belongs, a triangular outline when seen from above, with re-entering base and sides and somewhat angular rounded corners, but has no anal snout; anal system placed on the actinal side. Seen in profile, the apex is anterior, corresponding with the abactinal system. The test is uniformly covered with small tubercles carrying small slender spines, with the exception of a few larger tubercles near the abactinal area in the interambulacral spaces, along the actinal keel and the anterior interambulacral spaces of the actinal side, and round the anal system. Seen endwise, the outline is that of a truncated cone. The color of the test is violet brown. — Station 147, 1,600 fathoms.

Spatagocystis Challengeri, A. Ag., nov. gen. & sp.

The new genera Spatagocystis, Cystechinus, Urechinus, and Genicopatagus are among the most interesting Echini ever discovered, on account of their decided affinities to the strange group of Pourtalesiæ,

as well as their similarity, in many respects, to such cretaceous forms as Holaster, Cardiaster, and Ananchytes.

The present genus has a thin test, an outline from above resembling Holaster, but when seen in profile a well-developed actinal anal snout shows its affinity to the Pourtalesiæ. Seen in profile, the outline is regularly arched until it reaches the posterior extremity, which is pointed, projecting above the anal snout. This genus has a short but deeply sunken actinal groove and a small anal pouch. The color of the test of this species is pinkish, sparsely covered on the abactinal side by slender sharp spines of a uniform length. On the actinal side the spines are larger. — Station 157, 1,950 fathoms; Station 147, 1,600 fathoms.

Urechinus naresianus, A. Ag., nov. gen. & sp.

Urechinus and Cystechinus have not the sunken actinal groove which characterizes the Pourtalesiæ. In these genera the actinostome is more or less central, and does not differ materially in its structure or position from that of the more normal Spatangoids. The structure of the ambulacra, however, is, as in Pourtalesiæ and the other deep-water forms allied to them, quite different from that of the Spatangoids, with which externally they present many points of resemblance. Urechinus in outline and general appearance resembles, at first glance, Neolampas, but in the structure of the test it is more closely allied to Cystechinus, having like it a nearly flat actinostome and large ambulacral plates. The anal system alone recalls Neolampas by its position in a shallow groove placed above the ambitus. The young specimens differ but little from the older stages, the interambulacral projection over the anal system alone is not quite so prominent, and the actinostome less sunken. The number of primary tubercles in younger stages is limited to one for each plate, only becoming more numerous in older specimens when the whole test is thickly covered with fine slendar miliary and secondary spines. The spines are yellowish white, the test of a reddish brown color or pinkish color. The lower surface of the test closely tuberculated. — Station 147, 1,600 fathoms; Station 146, 1,375 fathoms; Station 158, 1,800 fathoms.

Cystechinus, A. Ag., nov. gen.

This genus has the general appearance of Ananchytes, with the simple ambulacral system of the Pourtalesiæ; actinostome much less labiate than in that group of Spatangoids. This genus and Urechi-

nus, as well as Homolampas and Palæotropus, with the actinostome nearly in one plane, form a ready transition to the actinostome of the Nucleolidæ and Echinolampadæ by the additional development of the interambulacral tubercles in immediate proximity to the actinostome and their crowding together to form bourrelets more or less prominent, and thus pass into such types as Neolampas, which have the simple ambulacra of this group, with the actinostome of the Echinolampadæ proper.

Cystechinus Wyvillii, A. Ag., nov. sp.

The outline of test seen from above is nearly elliptical, slightly broader anteriorly across the actinostome. Seen endwise, the outline is conical, with rounded apex and sides gradually rounding to ambitus. Actinal surface flat, slightly sunken actinostome, anal system near posterior edge on actinal side. Seen in profile, the outline is also conical, with rounded apex placed slightly posteriorly (apex and apical system coincide). The test slopes, with slightly re-entering sides towards the anterior and posterior extremities, passing into ambitus with a rather abruptly rounded outline near edge of test. The whole test is covered with short, sharp spines, carried by the few large tubercles arranged on the primary plates. Ridges radiating from the centre of each plate give to the side of the test, when denuded, a peculiarly ornate appearance. The color of the test is violet, spines of same color, darker. Test quite thin and very variable in outline according to age. Young specimens are quite flat.—Station 146, 1,375 fathoms; Station 147, 1,600 fathoms; Station 158, 1,800 fathoms.

Cystechinus clypeatus, A. Ag., nov. sp.

Judging from the fragments of the test of this species, it must have grown to a very large size, probably five or six inches in diameter. It differs from the preceding species in having a much shorter test; the arrangement of the plates of the anal system is quite different in this and the preceding species. In *C. clypeatus*, although the specimens are larger, there are fewer plates covering the anal system than in *C. Wyvillii*; in this species the genital plates are also much larger in proportion. Judging from a fragment of the actinostome, the actinal surface was more closely covered with primary tubercles than in the preceding species. — Station 133, 1,900 fathoms; Station 205, 1,050 fathoms.

Cystechinus vesica, A. Ag., nov. sp.

This species is at once distinguished from its congeners by the flexible nature of the test. This is so thin that its mere weight out of alcohol is sufficient to change the shape of the test, which has, when seen in profile, much the appearance of an old felt hat. The outline of the flat actinal surface is regularly elliptical. The anal system is placed just beyond the edge of the ambitus; the whole actinal surface is more thickly covered by large primary tubercles than the abactinal part of the test, where they are more distant; the spines are short, slender, sharp; the color in alcohol is greenish brown. The most prominent character of this species is the large size of the plates of ambulacral area, resembling, in this respect, more Galerites than Ananchytes. — Station 153, 1,675 fathoms; Station 298, 2,225 fathoms.

Homolampas fulva, A. Ag., nov. sp.

The species on which this genus was originally established was quite small; it is therefore difficult to compare the two. Outline, seen from above, is slightly heart-shaped, greatest width near anterior extremity across abactinal system; anterior ambulacrum broadly re-entering anal extremity deeply indented. A few large tubercles in interambulacral spaces carry long curved spines; rest of test on abactinal side carries short slender spines of uniform length, closely crowded together; on actinal side, posterior ambulacral areas bare; actinal plastron and lateral interambulacral spaces paved with large tubercles regularly arranged and carrying moderately long curved spines; subanal fasciole broad, pentagonal in outline. Seen in profile, test slopes regularly from apex, the short side anteriorly, the long side towards anal extremity, which is anteriorly truncated; color in alcohol, yellowish. — Station 271, 2,475 fathoms.

Argopatagus vitreus, A. Ag., nov. gen. & sp.

This genus is allied to Homolampas. It has, like it, a subanal fasciole, but no lateral fasciole, a more labiate actinostome. The abactinal surface is covered by distant primary tubercles of uniform size both in ambulacral and interambulacral areas. They are more numerous, but smaller, on the actinal surface.

In this species the apex and apical system are posterior, the outline from above is elliptical, slightly re-entering anteriorly. The test is quite low; actinal surface flat, regularly arching from apex to anterior and posterior extremities. The plates of the ambulacral and inter-

ambulacral areas of the abactinal side are of very uniform size, those of the bivium being, however, somewhat larger than those of the trivium. Station 191, 800 fathoms.

Paleopneustes Murrayi, A. Ag., nov. sp.

A number of large reddish-brown specimens were collected, unfortunately all nearly of the same size, so that I am unable to determine if the presence of a more or less well defined lateral fasciole is a sufficient reason for separating this species from the typical Paleopneustes, in which this fasciole either does not exist, or only in a very rudimentary condition. This species is at once separated from the West Indian species by the lesser height of the test, the smaller actinal plastron, the far greater length of the petaloid ambulacra, the proportionally larger primary tubercles on the abactinal side of the test, and the shorter truncated plane of the posterior extremity in which the anal system is placed. — Station 232, 345 fathoms.

Genicopatagus affinis, A. Ag., nov. gen. & sp.

This genus has striking affinities with Holaster, Toxaster, and Cardiaster. The lateral ambulacra and the odd ambulacrum have an identical structure, as in Toxaster, the ambulacra are slightly sunken, the double pores giving the ambulacra above the ambitus a slight petaloid appearance, much as in Paleopneustes. Seen in profile, the test is hemispherical, with prominently labiate actinostome and a flat actinal surface. The primary tubercles occupy the central part of the plates on the abactinal side of the test. On the actinal side the primary tubercles are large and prominent in the interambulacral areas. The ambulacral plates carry but a few secondary tubercles. The anal system is placed half-way between the ambitus and the abactinal system. The color of the test varies from pinkish to yellowish green.— Station 157, 1,950 fathoms.

Hemiaster gibbosus, A. Ag., nov. sp.

Seen in profile, the anal extremity is nearly vertically truncated, the apex is close to the posterior edge, thence the test slopes gradually to the anterior extremity, somewhat beyond the apical system, this is also vertically truncated and rounded, the actinal line is quite flat. Seen from above, the outline is elliptical, widest at posterior extremity. Test covered with tubercles of uniform size and equally distributed over the plates, except in the lateral posterior interambulacra, where the plates are comparatively bare, as well as on the actinal surface,

where the tubercles are larger and on the actinal plastron and interambulacral spaces; peripetalous fasciole broad pentagonal in outline; anal system quite small; anal groove shallow. — Station 232, 345 fathoms; Station 191, 800 fathoms.

Hemiaster zonatus, A. Ag., nov. sp.

The specimens of Hemiaster collected by the *Challenger* in the vicinity of the locality from which Loven's *H. expergitus* was obtained cannot be referred to it at present, although the differences between them may be due merely to age. In this species the spines are uniformly distributed over the whole abactinal surface of the test, the anal groove is deeper than in the preceding species, and the peripetalous fasciole is also broader. This species is more globular in shape, and closely allied to the cretaceous *H. prunella*. — Station 126, 750 fathoms.

Rhinobrissus hemiasteroides, A. Ag., nov. sp.

This is a much smaller species than the one which I figured in the Revision of the Echini, and it is referred to the genus with some doubt, as this species presents characters which remind us strongly of Metalia (the peripetalous fasciole) and of Brissopsis (anal fasciole), and even of Brissus proper. It has, like Rhinobrissus, the odd ambulacrum flush with the test, as well as the remarkably broad actinal ambulacral areas round the actinostome, and the great length of the spines in the lateral posterior interambulacra on the actinal side. It has, however, the lateral petals much as in Metalia proper, as well as its subanal fasciole, without the large anal branch so prominent in Rhinobrissus. The apex corresponds, also, as in Metalia, with the abactinal system, and is nearer the anterior extremity, which is posterior in Rhinobrissus. The spines of the abactinal surface are short, of uniform size, whitish color in alcohol. — Tahiti Harbor, 20 fathoms.

Schizaster claudicans, A. Ag., nov. sp.

This pretty little Schizaster is readily distinguished from its congeners by its high posterior extremity, nearly vertical, the sharp narrow clean-cut lateral fasciole, and the deeply sunken ambulacral petals fringed by an indistinct peripetalous fasciole. It has a narrow actinal plastron; anal opening placed immediately under the abactinal edge of the posterior interambulacral keel. Abactinal surface covered by close uniform tuberculation above the ambitus; odd anterior ambulacral petal shorter than the anterior pair of petals. — Station 192, 129 fathoms.

Schizaster japonicus, A. Ag., nov. sp.

Differs from *S. ventricosus* in having the posterior ambulacra proportionally longer, and forming a more acute angle with the longitudinal axis. It has a very distinct lateral and subanal fasciole; keel of median posterior interambulacral space forming a high crest at that extremity of the test, while *S. ventricosus* is remarkable for its comparatively flattened and rounded posterior extremity; ambulacra also more deeply sunken, much as in *S. canaliferus* and *S. Philippii*. These characters are early developed, and can serve, even in quite small specimens, readily to distinguish the two species. — Off Yokohama, 8–50 fathoms.

XV.

CONTRIBUTIONS TO AMERICAN BOTANY.

BY SERENO WATSON.

Presented May 14, 1879.

I. *Revision of the North American Liliaceæ.*

THE order *Liliaceæ*, as outlined by Dr. Gray in the last edition of his Manual (1867), and as now generally understood by botanists, presents such a diversity in its characters and their combinations that it is by no means easy to satisfactorily group the genera according to their affinities, or to arrange them in any seemingly natural sequence or sequences. The difficulty is not much diminished, but rather increased, when the question is confined to the genera of a limited geographical area; hence, in the following attempt at a classification of the fifty genera that are found in North America, their relations to the rest of the order have been in some measure taken into account.

If the character of a baccate as distinguished from a capsular fruit be considered a subordinate one (as seems to be necessary), a division of the genera may be made into three series or suborders, which, notwithstanding exceptions, are on the whole pretty clearly defined. The first and largest of these is prominently distinguished by its scarious floral bracts, persistent nerved perianth, perigynous stamens with introrse anthers, an undivided persistent style, and a loculicidal fruit (if capsular). This includes much the larger portion of the genera which have usually been considered as belonging to the capsular *Liliaceæ*, as well as most of the *Asparagineæ*. Both of the other divisions have the stamens hypogynous or nearly so, with more or less extrorse anthers, and the floral bracts are more or less foliaceous or are wanting. Both also always have distinct perianth-segments and unjointed pedicels. But one has a nerveless deciduous perianth, the styles (when present) more or less united, and the fruit a loculicidal capsule or a berry; to this belong the *Lilieæ* or *Tulipeæ* proper, the *Uvularieæ* and the *Trillieæ*, as here defined, and a few other

genera. The other division, corresponding nearly to the old order *Melanthaceæ*, has distinct styles and a septicidal capsule conjoined with a persistent nerved perianth.

The subdivision into tribes is here based upon the characters of the inflorescence, and such others as can be used without separating evidently allied genera, to avoid which it is sometimes found necessary to lay little stress either upon the degree of union of the segments of the perianth or upon root-characters. The grade of the tribes is equalized so far as possible by reducing the less positively marked groups to the rank of subtribes, though some isolated genera are still left, which refused to be so degraded. As respects the citation of authorities under the specific descriptions, only the more important synonyms and figures are usually referred to. Much indebtedness is acknowledged to the recent revisions of various portions of the order by Mr. J. G. Baker of Kew, although his conclusions are not in every case adopted. It is a source of regret that his last paper upon the "*Colchicaceæ*" has not yet been issued, and that the present article, which has been delayed for some time with the hope of benefiting by it, must be completed without such assistance.

SERIES I. Floral bracts present and more or less scarious. Perianth persistent; segments 1–several-nerved. Stamens perigynous; anthers introrse. Style undivided, persistent. Capsule loculicidally dehiscent. Seeds more or less turgid, ascending, with close black testa. Leaves with approximate longitudinal nerves and transverse veinlets. Pedicels often jointed.

Exceptions. Style and perianth deciduous in *Odontostomum*. Style deciduous in *Chlorogalum* and *Hesperaloe;* sometimes wanting and capsule sometimes baccate or septicidal in *Yucca*. Fruit baccate or indehiscent, with light-colored seeds, in *Convallarieæ* and *Nolineæ*. Seeds dark brown in *Odontostomum;* horizontally flattened in *Hesperocallis* and *Yucceæ*.

SUBSERIES I. Inflorescence umbellate, upon a naked scape arising from a corm or bulb; sessile upon a short rootstock in *Leucocrinum*.

TRIBE I. **Allieæ.** Bracts (usually 2) broad and spathaceous: capsule more or less deeply lobed, the filiform style jointed upon the axis: seeds one to several in each cell, angular or subovate: perianth cleft nearly to the base; segments 1-nerved: pedicels not jointed: bulb mostly tunicated.

1. ALLIUM. Flowers deep rose-color to white. Capsule subglobose or obovate, deeply lobed and often crested: base of the style enclosed between the lobes and jointed upon the short axis: cells 1–2-ovuled at the base. Filaments usually dilated at base. Bracts 2 to 4. Leaves one to several. Scape from a tunicated bulb (sometimes rhizomatous) or rarely a coated corm. Taste and odor strongly alliaceous. — In our species the sheaths of the

leaves rarely extend at all above ground, the bracts are never elongated, and the filaments are without cusps or teeth, the bases united into an adnate disk (except in *A. tricoccum*).

2. NOTHOSCORDUM. Flowers greenish or yellowish white. Capsule oblong-obovate, somewhat lobed, obtuse, with the style obscurely jointed on the summit; cells several-ovuled. Filaments filiform, distinct, adnate at base. Bracts 2. Leaves several. Bulb tunicated: not alliaceous.

TRIBE II. **Milleæ.** Bracts several, not spathaceous, distinct: capsule not lobed (or slightly so), acute, and beaked by the mostly stout (at length splitting) style: seeds few to several in each cell, angular: perianth-segments more or less united or distinct, 1-nerved or rarely closely 2–3-nerved: scape from a membranous- or fibrous-coated corm.

* Perianth parted to the base or nearly so; segments spreading, closely 2–3-nerved: stamens in one row at the base; anthers versatile: capsule obovate or subglobose, sessile or nearly so; cells several-seeded.

3. MUILLA. Flowers greenish-white. Filaments filiform, naked, adnate at base. Pedicels not jointed. Leaves several.

4. BLOOMERIA. Flowers yellow, on jointed pedicels. Filaments elongated, free, surrounded at base by a somewhat cup-shaped and winged appendage. Leaf solitary.

* * Perianth evidently gamophyllous, with the stamens on the throat.

+ Perianth funnel-form; segments 1-nerved (very rarely 2–3-nerved in *Brodiæa*): pedicels jointed (except in *Androstephium*).

5. BRODIÆA. Perianth more or less narrowly funnel-form, not contracted at the throat, nor saccate or but very slightly so at base, blue-purple or white or yellow. Stamens 6, in one or two rows with winged or naked filaments, or 3 and alternate with as many staminodia. Capsule ovate to oblong.

6. STROPHOLIRION. Flowers rose-colored, the short broadly turbinate tube 6-saccate, contracted at the throat, about equalling the spreading limb. Stamens 3, alternate with 3 ligulate staminodia; filaments winged; anthers basifixed. Capsule nearly sessile, ovate, acuminate.

7. BREVOORTIA. Perianth-tube broad, 6-saccate at base, deep scarlet, several times longer than the short erect or reflexed yellowish limb. Stamens 3, alternate with 3 broad truncate staminodia; anthers basifixed, nearly sessile. Capsule long-stipitate, ovate, acuminate.

8. ANDROSTEPHIUM. Flowers pale lilac, the cylindrical tube about equalling or shorter than the somewhat spreading limb. Stamens 6, in one row; the filaments united to form an erect tubular

crown, with bifid lobes alternate with the oblong versatile anthers. Capsule sessile, subglobose-triquetrous. Seeds large.

+- +- Perianth salver-form; segments 3-nerved: pedicels not jointed.

9. MILLA. Flowers white, greenish outside with stout green midveins, the tube narrowly turbinate. Stamens nearly sessile, in one row, naked: anthers basifixed. Capsule sessile, oblong-obovate.

TRIBE III. **Leucocrineæ.** Acaulescent; flowers on subterranean pedicels in a sessile umbel, with elongated linear bracts, from a short rootstock: perianth salver-form, with linear tube and several-nerved segments: stamens in one row near the throat; anthers basifixed: capsule sessile, triangular-obovate; seeds obovate, angled, several in each cell.

10. LEUCOCRINUM. Flowers white, very fragrant. Filaments filiform; anthers linear. Style slender and elongated, tubular, dilated at the summit. Leaves narrowly linear, surrounded at base by scarious bracts. Floral bracts sheathing the pedicels.

SUBSERIES II. Inflorescence racemose or paniculate.

TRIBE IV. **Phalangieæ.** Flowers mostly small, with distinct segments, on jointed naked pedicels with small bracts, in simple or usually paniculate racemes: stem somewhat leafy or naked, from a tunicated bulb or rootstock or fleshy-fibrous root: anthers versatile.

* Capsule obovate or oblong: seeds angled, several in each cell: flowers rather large, racemose on a naked scape from a tunicated bulb.

11. CAMASSIA. Flowers blue (rarely white), slightly gibbous; segments 3–7-nerved, spreading. Base of the style persistent. Seeds black and shining. Raceme open. Leaves linear, flat.

* * Capsule oblong; cells several-seeded: seeds angular and somewhat flattened: pedicels (usually fascicled) jointed near the middle: root fleshy-fibrous.

12. HESPERANTHES. Flowers yellow or yellowish; segments spreading from the base, 3–5-nerved in the middle, twice longer than the stamens, at length twisted over the ovary. Filaments muricate, longer than the anthers. Style elongated and very slender, becoming declinate. Leaves narrowly linear and grass-like, surrounded at base by the fibrous remnants of older ones. — *Anthericum*, subgen. *Hesperanthes*, Baker, Journ. Linn. Soc. 15. 317.

* * * Capsule triangular-obovate, 3-lobed; cells (2-ovuled) 1–2-seeded: seeds obovate: pedicels (mostly solitary) jointed at the summit: stem from a tunicated bulb or rootstock. — Subtribe CHLOROGALEÆ.

13. SCHŒNOLIRION. Flowers yellow or whitish, in loose simple or sparingly panicled racemes, the perianth not scarious nor becoming connivent or twisted over the ovary; segments distinctly

3–5-nerved, exceeding the stamens. Style short. Capsule de pressed globose, deeply-lobed. Seeds subglobose, shining. Stem naked, scaly and thickened at base, from a thick rootstock. Leaves rather rigid, few-nerved, very narrow, flat. Pedicels slender, exceeding the flowers and bracts. Atlantic States.

14. HASTINGSIA. Flowers white or greenish, in densely many-flowered sparingly panicled racemes, the perianth lax and scarious; segments closely 3- (apparently 1-) nerved, equalling the stamens. Style short. Ovary oblong-ovate, not deeply lobed. Stem naked or sparingly leafy, from a tunicated bulb. Leaves broader and more fleshy. Pedicels stout, much shorter than the flower and bract. California.

15. CHLOROGALUM. Flowers white or pinkish, in loose paniculate racemes; perianth at length twisted over the ovary; segments distinctly 3-nerved. Style long, deciduous. Seeds blackish, somewhat rugose. Bulbs with membranous or densely fibrous coats. Leaves with undulate margins. California.

TRIBE V. **Odontostomeæ.** Flowers small, on solitary bracteolate not jointed pedicels in an open panicle; the stem leafy at base, from a fibrous-coated corm: perianth salver-form, deciduous: stamens on the throat; anthers subglobose, basifixed, dehiscent at the summit: style deciduous.

16. ODONTOSTOMUM. Flowers yellowish, the cylindrical 12-nerved tube about equalling the at length reflexed 5-nerved segments. Stamens very short, alternating with as many small linear staminodia. Capsule triangular-obovate, 3-lobed; cells (2-ovuled) 1-seeded. Seeds obovate, with dark brown testa. California.

TRIBE VI. **Convallarieæ.** Flowers on jointed pedicels in terminal racemes or racemose panicles or in axillary fascicles, upon leafy simple stems (or a naked scape in *Convallaria*) from creeping rootstocks: perianth 6-cleft or of 4 or 6 distinct 1-nerved small glandless segments: style short, usually somewhat persistent; stigma slightly lobed: fruit a globose berry: seeds 1 to several in each cell, ascending or horizontal, subglobose, with close thin testa. Stem naked below (scarious-sheathed at base): leaves cordate to lanceolate.

* Perianth gamophyllous, campanulate or cylindrical, at length deciduous.

17. CONVALLARIA. Acaulescent. Flowers white, campanulate, cleft to the middle, on recurved pedicels with small lanceolate bracts, in a simple one-sided raceme upon a slender curved scape. Stamens near the base; anthers ovate-oblong, sub-basifixed. Style stout, persistent; stigma triangular: ovules 2 or 3 pairs in each cell. Berries red, usually 6-seeded. Leaves 2 or 3, the long petioles convolute and stem-like.

18. POLYGONATUM. Flowers white or greenish, cylindric, 6-lobed at the summit, on mostly naked pedicels in axillary pedunculate fascicles (sometimes solitary). Stamens on the tube; anthers linear-oblong, versatile. Style slender, deciduous; stigma obscurely 3-lobed. Ovules 1 to 3 pairs in each cell. Berry blue or black; cells 1–2-seeded. Stem erect or curved; leaves sessile or nearly so; bracts caducous, minute.

* * Perianth-segments distinct, small, spreading, persistent.

19. SMILACINA. Flowers white, trimerous, solitary (in our species), with minute scarious bracts, in a racemose panicle or simple raceme on an erect leafy stem. Stamens at the base; filaments subulate; anthers short-oblong, versatile. Style short, thick, persistent; stigma 3-lobed. Ovules a pair in each cell. Berry red or blue-black, 1–3-seeded. Leaves mostly sessile.

20. MAIANTHEMUM. Flowers white, dimerous, solitary or fascicled, in a simple raceme upon a low 2–3-leaved stem. Filaments filiform. Berry red. Leaves ovate- to lanceolate-cordate, mostly petiolate. Otherwise as *Smilacina*.

TRIBE VII. **Nolineæ**. Flowers very small, whitish, polygamo-diœcious, on short jointed solitary or fascicled pedicels, in a simple or compound panicle on a leafy stem from a thick woody caudex or rootstock: perianth campanulate; segments 1-nerved: anthers ovate-cordate, versatile: stigmas very short, distinct, sessile or on a short style: ovules 6, in pairs at the base of the ovary: fruit dry and thin, indehiscent or bursting irregularly, 1–3-celled, 1–3-seeded: seed subglobose, with thin light-colored testa: leaves numerous, crowded, narrowly linear, elongated, rigid, striate, with rough or armed margins.

21. NOLINA. Flowers polygamo-diœcious in a loosely racemose simple or compound panicle; segments oblong-ovate, usually acutish. Stamens included. Stigmas sessile or nearly so. Fruit rounded, deeply triquetrous, thin-membranous, 3-celled, 1–3-seeded, bursting irregularly. Seeds ovate to globose. Leaves unarmed. Naked caudex slender with a dilated base, or very short or wanting. Fertile flowers mostly solitary and on longer pedicels than the staminate.

22. DASYLIRION. Flowers diœcious in dense racemes forming a narrow compound panicle, the tall leafy flowering stem terminating a stout naked cylindrical caudex. Perianth-segments oblong-obovate, obtuse. Stamens exserted. Style short. Fruit triangular and 3-winged, 1-celled, 1-seeded, coriaceous and indehiscent. Seed obtusely triangular. Leaves usually armed with hooked spines. Staminate flowers nearly sessile.

TRIBE VIII. **Hemerocallideæ.** Flowers large, on naked jointed pedicels with conspicuous bracts, simply racemose upon a leafy stem from a tunicated bulb (or fleshy-fibrous roots): perianth funnel-form, 6-cleft: stamens on the throat; anthers versatile: seeds (in our genus) horizontal, flattened, numerous, black.

23. HESPEROCALLIS. Perianth white, cleft to below the middle; segments several-nerved. Anthers linear. Capsule ovate-oblong, deeply lobed. Raceme few-flowered, the stout pedicels jointed at the summit.

TRIBE IX. **Yucceæ.** Flowers racemose-paniculate upon a stout leafy or leafy-bracteate stem from a stout caudex or thick and often branching rootstock; segments distinct: anthers versatile, sagittate: seeds numerous, in 2 rows in each cell, horizontal, flattened, black. Leaves numerous and crowded, linear, thick and more or less rigid: pedicels jointed at the summit.

24. HESPERALOE. Perianth narrowly cylindric, reddish; segments linear, about 7-nerved. Filaments subulate-filiform, smooth; anthers linear-oblong. Style filiform, deciduous; stigma small, capitate. Capsule loculicidal, 3-celled. Caudex very short, sending up a slender sparingly bracteate flowering stem: leaves linear, deeply channelled, with filiferous margins: flowers fascicled, erect.

25. YUCCA. Perianth campanulate, white or whitish; segments ovate-lanceolate, many-nerved. Filaments clavate, often papillose; anthers small. Style stout and persistent (or none); the emarginate stigmas more or less connate into a stigmatic tube. Fruit baccate, or capsular and septicidal or loculicidal, incompletely 6-celled. Rarely acaulescent, usually with a stout woody caudex, often tall and tree-like: leaves linear-lanceolate, spinescent at apex: flowers usually solitary and nodding.

SERIES II. Floral bracts none or foliaceous. Perianth deciduous; segments distinct, net-veined. Stamens hypogynous, or at the very base; anthers more or less extrorse. Styles united at least at base, deciduous. Fruit loculicidally dehiscent or berry-like. Seeds turgid, with thin close brown testa. Flowers mostly large and showy, solitary or racemose or pseud-umbellate. Pedicels not jointed. Leaves with anastomosing veinlets.

Exceptions. Perianth persistent in *Lloydia* and *Trillium*; segments several-nerved in *Lloydia*, *Clintonia*, *Medeola*, and *Scoliopus*. Anthers usually introrse in *Trillium*. Style persistent in *Lloydia*; stigmas sessile and persistent in *Calochortus*, *Scoliopus*, and *Trillium*. Capsule mostly septicidal in *Calochortus*. Seeds flat and horizontal in most *Lilieæ*; crustaceous in *Clintonia*. Leaves with transverse veinlets in *Lloydia* (?), *Calochortus*, *Scoliopus*, and most *Uvularieæ*.

TRIBE X. **Lilieæ.** Flowers terminal or axillary or subumbellate, upon a more or less leafy stem from a bulb or coated corm, campanulate or funnel-form; segments usually nearly equal and similar, bearing a nectary or gland: capsule many-seeded: seeds horizontal or ascending.

* **Stem simple, strict, leafy, from a scaly bulb: floral bracts leaf-like: anthers versatile: styles elongated: capsule not triquetrous: seeds flat, horizontal.**

26. LILIUM. Perianth-segments oblanceolate, more or less spreading or recurved, often dotted or spotted; nectary a linear groove. Anthers distinctly versatile. Style undivided. Bulb-scales lanceolate.

27. FRITILLARIA. Perianth-segments broader and concave, often mottled; nectary a shallow pit. Anthers more obscurely versatile. Styles united to the middle or throughout. Bulb-scales mostly short, very thick.

* * **Stem simple, low, lax, from an oblong membranous-coated corm, bearing a pair of dilated leaves, without floral bracts: anthers basifixed: styles elongated: capsule triangular or triquetrous: seeds ascending, turgid, brownish.**

28. ERYTHRONIUM. Perianth-segments oblanceolate, strongly revolute, mostly callous-toothed at base each side of the grooved nectary. Styles usually distinct above. Seeds obovoid, angled, the testa loose and rugose at top.

* * * **Stem simple, dwarf, from a small tunicated bulb: leaves linear, without veinlets: perianth persistent, the equal segments 3-nerved, with a naked obscure gland at base: anthers very small, basifixed: style slender, undivided, persistent: capsule triquetrous: seeds horizontal, flat. — Subtribe LLOYDIEÆ.**

29. LLOYDIA. Perianth small, spreading, white with purplish veins and base. Stem slender, leafy, usually 1-flowered; the bulb upon an oblique rhizome, covered by the persistent scarious bases of the nearly filiform leaves. Arctic or alpine.

* * * * **Stem usually branched, from a coated corm, sparingly leafy: leaves with transverse veinlets: perianth of unequal segments, the outer smaller, somewhat greenish and sepaloid, the inner dilated and mostly with pitted and bearded or crested glands: anthers basifixed: stigmas sessile, distinct, recurved, persistent: capsule usually deeply triquetrous, mostly septicidal: seeds ascending, with light-colored spongy testa, rarely flat and horizontal. — Subtribe CALOCHORTEÆ.**

30. CALOCHORTUS. Flowers mostly large and showy, broadly campanulate. Stem usually lax or flexuous, from a membranous- or rarely fibrous-coated corm.

TRIBE XI. **Uvularieæ.** Flowers terminal or pseud-axillary, solitary or subumbellate, with naked pedicels on leafy branching stems (or in *Clintonia* on a scape-like peduncle) from a short or creeping rootstock: perianth narrowly campanulate; segments oblanceolate, with a nectariferous groove at the narrow subgibbous base: anthers linear: styles linear, more or less united, stigmatic down the inside: fruit a loculicidal or tardily dehiscent capsule, or berry-like: seeds pendulous: stems scaly-bracted below: leaves dilated, with numerous nerves and transverse veinlets (reticulated in *Prosartes*).

31. Uvularia. Flowers few (1 to 3), solitary, terminating the stem or leafy branches, pendulous, yellow; segments acuminate, obtusely gibbous and with a callus or ridge each side of the deep nectary. Anther-cells adnate to the prolonged connective. Styles united to the middle. Capsule coriaceous, depressed obovate, obtusely 3-lobed, loculicidal at the summit. Seeds 1 or 2 in each cell, globose, brown, half covered by a thin white aril. Stem terete, from a short rootstock with fleshy-fibrous roots. Leaves perfoliate, smooth on the margin.

32. Oakesia. Flowers few, solitary, on short pedicels opposite the leaves, pendulous, yellow; segments obtuse or acutish, carinately gibbous and without callosities. Stamens and styles as in the last. Capsule membranous, elliptical, acutish at each end or shortly stipitate, triquetrous and acutely winged, very tardily dehiscent. Seeds 1 to 3 in each cell, globose, brown, with a very tumid spongy brown rhaphe. Stem acutely angled, from a slender creeping rootstock. Leaves sessile, clasping, with scabrous margins.

33. Streptopus. Flowers more numerous, apparently axillary, the pedicel often geniculate upon a peduncle (a second or third pedicel and flower sometimes developed), pendulous, greenish-white or purplish; segments acuminate, recurved above. Anthers sagittate, on short deltoid or subulate filaments, acute or setaceously acuminate. Styles united. Fruit a reddish subglobose slightly 3-lobed berry. Seeds few to many in each cell, oblong, longitudinally striate, light-colored. Leaves clasping.

34. Prosartes. Flowers in fascicles (1–6-flowered) terminating the branches, white or greenish, suberect or pendulous; segments acute or acuminate. Anthers on slender filaments, oblong, obtuse, dehiscing laterally. Styles united. Ovules 1 to 3 pairs in each cell. Fruit a somewhat fleshy obtusely lobed reddish berry. Seeds subglobose to oblong, with very thin close light-colored testa. Leaves with reticulated veinlets.

35. Clintonia. Flowers solitary or umbellate upon a naked scape-like peduncle, white, greenish, or rose-colored, erect or nodding; segments obtuse or acutish. Anthers on slender filaments, oblong to linear, dehiscing laterally. Ovary 2–3-celled: styles united; stigma 2–3-lobed (ovary 2-celled and stigma only slightly 2-lobed in our species). Fruit a thin slightly lobed ovoid blue berry. Seeds smooth, brownish, crustaceous. Root-stock slender, creeping: leaves radical, large, oblanceolate, sheathing, ciliate.

TRIBE XII. **Trillieæ.** Flowers terminal, on solitary or umbellate naked pedicels subtended by a pair or whorl of leaves upon an otherwise naked stem (a second whorl in *Medeola*), from a thick or tuberous rootstock. Perianth spreading, the segments mostly dissimilar in the two series, the outer often herbaceous, without glands. Stigmas sessile or nearly so, linear, channelled, persistent (except in *Medeola*). Fruit dry or berry-like. Seeds horizontal or ascending. Leaves broadly ovate to oblanceolate, mostly net-veined.

* Flowers umbellate; segments dissimilar, all petaloid, several-nerved, deciduous: stamens 3; anthers attached above the base: stigmas persistent: fruit dry, 1-celled with parietal placentæ, many-seeded. Nearly acaulescent; leaves a radical pair, with numerous parallel nerves and transverse veinlets. — Subtribe SCOLIOPEÆ.

36. SCOLIOPUS. Flowers purplish, on slender flexuous pedicels; outer segments lanceolate, inner narrowly linear. Anthers oblong; filaments short, filiform-subulate. Style short; stigmas recurved. Fruit thin-membranous, bursting irregularly, triquetrous, oblong, acute at each end, placentiferous at the angles. Seeds oblong, striate longitudinally, with light-colored testa, dark chalaza and crested rhaphe. Rootstock short with numerous fleshy-fibrous roots: whole plant brown-punctate, glabrous.

* * Flowers umbellate; segments similar, several-nerved, deciduous: anthers attached above the base: stigmas (3 or 4) sessile, deciduous: fruit a few-seeded berry: stem slender, bearing two distant whorls of 3-nerved net-veined leaves. — Subtribe MEDEOLEÆ.

37. MEDEOLA. Flowers greenish-white, on recurved pedicels; segments oblong, obtuse, recurved. Anthers oblong; filaments filiform. Stigmas elongated, divaricate. Berry subglobose, purple. Seeds roundish. Rootstock tuberous with slender rootlets.

* * * Flowers solitary; outer segments herbaceous; inner petaloid, net-veined, marcescent: anthers adnate, usually introrse: stigmas sessile, persistent: fruit a many-seeded berry: stem with a single whorl of 3–5-nerved net-veined leaves.

38. TRILLIUM. Flowers white to purple, sessile or pedicellate; segments ovate to linear-lanceolate, more or less spreading or recurved, the outer smaller. Anthers linear; filaments linear-subulate. Stigmas linear or subulate, usually recurved above. Fruit reddish, ovate or subglobose, 3-lobed or more often 6-angled or -winged, occasionally 1-celled with parietal placentæ. Seeds ovate, scarcely striate, with thick rhaphe.

SERIES III. Perianth persistent; segments distinct, 1–several-nerved. Stamens at the base of the perianth; anthers extrorse, versatile, small, distinctly 2-celled except in *Veratreæ*. Styles or sessile stigmas distinct. Capsule septicidal, triquetrous. Seeds ascending, with loose testa or more or less

appendaged, not black. Inflorescence a simple raceme or panicle; pedicels solitary, not jointed, with green or greenish or rarely scarious bracts, or naked. Leaves with transverse veinlets, except in *Helonieæ*.

Exceptions. Anthers introrse in *Tofieldieæ;* filaments adnate in *Melanthium*. Style none or undivided in *Narthecium*. Capsule loculicidal in *Narthecium* and *Xerophyllum*. Seeds horizontal in *Tofieldia* and *Pleea*.

TRIBE XIII. **Veratreæ.** Perianth-segments several-nerved, often adnate to the base of the ovary. Anthers cordate or reniform, dehiscent by a continuous slit and peltate after opening: stigmas terminal: capsule membranous, 3-beaked by the short persistent styles: seeds with thin loose testa, not caudate or appendaged: stem usually leafy, from a tunicated bulb or thick rootstock: leaves not rigid.

* Flowers usually polygamous: cells of the usually ovate-oblong capsule not divaricately divergent above, dehiscent to the base: seeds several (4 to many) in each cell, not turgid, oblong to linear, angled, or flattened and margined.

+- Inflorescence pubescent, racemose-paniculate, usually staminate below: seeds flat, whitish, mostly broadly margined: stems tall and leafy, from a thick rootstock with fleshy-fibrous roots: leaves linear-oblanceolate to suborbicular.

39. MELANTHIUM. Flowers cream-color or greenish, rotate, shorter than the slender spreading pedicels; segments orbicular to oblanceolate, conspicuously biglandular or glandless, the filaments adnate to the narrow claw; perianth free from the ovate-oblong capsule.

40. VERATRUM. Flowers cream-color, greenish, or purple, more or less spreading, usually exceeding the short stouter pedicels; perianth slightly adnate to the ovary; segments oblanceolate to rhombic-ovate, glandless or rather obscurely glandular. Leaves strongly nerved and more or less plicate.

+- +- Inflorescence glabrous: flowers perfect or polygamous: seeds linear to narrowly oblong, angled or slightly margined, more or less brown: root bulbous (except in one species of *Zygadenus*): leaves linear.

41. STENANTHIUM. Flowers white, greenish, or purple, nodding or subsessile in usually paniculate racemes. Perianth adnate to the base of the ovary; segments lanceolate, acuminate, without glands. Seeds 4 in each cell, angled or somewhat flattened.

42. ZYGADENUS. Flowers white or greenish, erect, in paniculate or simple racemes. Perianth often adnate at base; segments oblong-lanceolate to ovate, mostly glandular and usually somewhat narrowed at base. Seeds angled, rarely at all margined.

43. SCHŒNOCAULON. Flowers small, mostly green, nearly sessile in a simple many-flowered spike-like raceme (usually sterile

above), upon a naked scape. Perianth free; segments linear or linear-oblong, obtuse, without glands and nearly nerveless. Stamens long-exserted. Seeds brown, angled. Leaves elongated, dry and grass-like. Bracts very small, ovate, membranous. Bulb-coats becoming black and fibrous.

* * Flowers perfect: capsule short, the 1–2-seeded cells widely divergent above and dehiscent only at the summit: seeds ovate, with a (fleshy ?) reddish-brown coat. Bulbous.

44. AMIANTHIUM. Glabrous. Flowers white, much shorter than the pedicels, in a dense many-flowered simple raceme on a sparingly leafy stem. Perianth free; segments ovate-oblong, obtuse, glandless. Leaves linear, obtuse.

TRIBE XIV. **Helonieæ.** Inflorescence a simple raceme, without bracts, on a leafy stem from a thick tuberous rootstock; glabrous. Flowers perfect or diœcious, glandless. Styles linear, stigmatic down the inside, deciduous. Capsule membranous, obovate to oblong, ventrally dehiscent at the summit of the abruptly divergent cells. Seeds numerous, linear, ascending from near the base, appendaged or winged at each end. Leaves oblanceolate, thin; veinlets anastomosing.

45. HELONIAS. Flowers perfect, in a short dense raceme, purple or greenish; segments spatulate-oblong, several-nerved, shorter than the slender filaments. Capsule broadly obovate, deeply 3-lobed, the summit much depressed. Seeds narrowly linear with a short white appendage at each end. Stem scaly-bracteate.

46. CHAMÆLIRIUM. Flowers diœcious, in slender elongated racemes, white: segments narrowly linear-spatulate, 1-nerved, equalling the stamens, which are shorter and abortive in the pistillate flowers. Capsule oblong, slightly depressed and shortly lobed at the summit. Seeds flattened, margined, and winged at each end. Stem very leafy.

TRIBE XV. **Tofieldieæ.** Flowers perfect, on bracteolate pedicels, in a simple raceme on an equitant-leafy stem from a creeping rootstock. Perianth-segments narrow, without glands. Stamens 9 to 12 in *Pleea*; anthers introrse, short, ovate to linear. Styles distinct and persistent, or none; stigmas terminal. Capsule dehiscing to the base, loculicidal in *Narthecium*. Seeds numerous, small, mostly appendaged or caudate, brown. Leaves distichously equitant, much shorter than the stems.

47. TOFIELDIA. Flowers white or greenish, subtended by very small bracts and involucrate with 3 scarious verticillate and more or less united bractlets; perianth-segments oblong or obovate, 3-nerved, equalling the stamens. Anthers round-cordate, nearly basifixed; filaments narrowly subulate, naked. Styles short.

Capsule ovate to obovate, 3-beaked. Seeds horizontal, unappendaged or more or less caudate at the outer end.

48. PLEEA. Flowers few, greenish-white turning brown. Pedicels solitary in the axils of large foliaceous sheathing bracts, bibracteolate in the middle. Perianth-segments lanceolate, 1-nerved. Stamens 9 ("6 to 12"), in pairs on the outer sepals, included; filaments subulate, naked; anthers oblong-linear, sagittate. Styles short. Capsule coriaceous, ovate, 3-beaked. Seeds horizontal, linear, attenuate at base, caudate above.

49. NARTHECIUM. Flowers yellowish-green, the solitary pedicels subtended by a lanceolate bract and bearing a small linear bractlet. Perianth-segments linear-lanceolate, obscurely 3-nerved. Stamens included; filaments subulate, woolly; anthers linear-oblong. Style none; the slightly lobed stigma sessile upon the attenuated apex of the ovary. Capsule narrowly oblong, membranous, attenuate upward, splitting loculicidally into 3 valves. Seeds ascending from near the base of the axis, linear, with a long straight tail at each end.

TRIBE XVI. **Xerophylleæ.** Flowers perfect, on naked pedicels in a simple bracteate raceme, on a very leafy stem from a thick tuberous rootstock. Glands none. Styles linear, stigmatic down the inside, persistent. Capsule ovate, chartaceous, loculicidally dehiscent to the base, and sometimes septicidal. Seeds 2 to 4 in each cell, ascending, with loose thin testa, not appendaged or scarcely so. Leaves very narrow, dry, striate and rough-edged.

50. XEROPHYLLUM. Flowers white, on long spreading pedicels (erect in fruit), in a subpyramidal many-flowered raceme; segments ovate to oblong, 5–7-nerved. Styles reflexed or recoiled. Seeds oblong, somewhat angled, light-colored. Cauline leaves numerous, setaceous from a broader base. Bracts linear, elongated.

In addition to the above, other genera are represented by the following species that have become more or less widely naturalized in some sections of the Atlantic States: —

ORNITHOGALUM UMBELLATUM, Linn. The Star of Bethlehem; in moist meadows.

MUSCARI BOTRYOIDES, Mill. The Grape-Hyacinth; road-sides and copses.

HEMEROCALLIS FULVA, Linn. The Day-Lily; road-sides.

ASPARAGUS OFFICINALIS, Linn. Garden Asparagus: sea-coast and copses.

1. ALLIUM, Linn.

§ 1. Bulbs cespitose, narrowly oblong and crowning a more or less persistent rhizome; coats membranous, without peculiar reticulation: spathe mostly 2-valved: scape terete.

*** Leaves (2 or 3) elliptic-lanceolate: ovules solitary.**

1. A. TRICOCCUM, Ait. Bulb-coats fleshy-membranous, the outer becoming fibrous: scape 4 to 12 inches high: flowers greenish white, on short suberect pedicels; segments two or three lines long, the outer channelled, the inner flat: stamens short, hypogynous, with nearly distinct subulate filaments: capsule deeply lobed, not crested. — *A. triflorum*, Raf. New England to Wisconsin, and south to North Carolina and Kentucky.

*** * Leaves (several) linear: ovules a single pair.**

+ Leaves terete, hollow.

2. A. SCHŒNOPRASUM, Linn. Scape stout: umbel subcapitate: flowers rose-color; segments 4 or 5 lines long, acuminate: stamens included: capsule not crested. — *A. campanulæflorum*, Geyer. From Canada (New Brunswick) and the Great Lakes to the Columbia and Peace Rivers and N. Alaska; Europe and N. Asia.

+ + Leaves flat or channelled.

3. A. CERNUUM, Roth. Outer bulb-coats sometimes finely fibrous: scapes slender, ½ to 2 feet high: leaves 1 to 4 lines broad: umbel open, nodding: flowers numerous, on very slender pedicels, rose-colored or white; segments 2 or 3 lines long, broad and acutish: stamens and style exserted: capsule crested. — From the Alleghany Mountains to British Columbia, Oregon, Utah, New Mexico and Texas.

4. A. VALIDUM, Watson. Scape very stout, 1 to 2½ feet high, from a stout rhizome: leaves 2 to 8 lines broad: umbel often slightly nodding, with 2 to 4 bracts, densely many-flowered; pedicels short: flowers rose-colored or nearly white; segments 3 or 4 lines long, narrowly acuminate: stamens and style usually slightly exserted: capsule not crested, subglobose. — King's Rep. 5. 350. Oregon to N. California and N. Nevada.

5. A. BREVISTYLUM, Watson, l. c. Scape 1 to 1½ feet high, from a stout rhizome: leaves 2 to 4 lines wide: spathe 1-valved: umbel erect, few-flowered; pedicels 6 to 12 lines long: flowers deep rose-color; segments 4 or 5 lines long, narrow, long-acuminate, nearly twice longer than the stamens and style: capsule not crested. — Northwestern Wyoming to S. Utah.

6. A. HÆMATOCHITON. Bulb-coats deep red: scape a foot high or less: leaves about a line wide: umbel erect or nearly so, few–many-flowered; pedicels short: flowers 3 or 4 lines long, deep rose-color, especially on the midveins of the ovate-lanceolate acute segments: stamens and style included; filaments very slender: ovary truncate, with very short rounded crests; capsule obovate. — California (San Luis Obispo to Ojai; n. 462, Brewer).

§ 2. Bulbs globose to ovate, mostly solitary, not rhizomatous; coats fibrous or membranous: leaves narrowly linear, flat or channelled: scape terete or nearly so.

* Bulb-coats more or less fibrous: leaves several.

+– Capsule not crested: spathe usually 3-valved.

7. A. CANADENSE, Kalm. Bulb-coats somewhat fibrous: scape a foot high or more: umbel mostly bulbiferous (often with 2 or 3 flowers): flowers on slender pedicels (6 to 10 lines long), white or pinkish, 3 lines long; segments narrowly lanceolate, obtusish, equalling or somewhat exceeding the stamens: filaments slightly broader below. — *A. longicaule*, Hornem.? From Canada to Florida and Texas.

8. A. MUTABILE, Michx. Like the last: bulbs densely and coarsely fibrous-coated: scape a foot or two high: umbel few–many-flowered, rarely or never bulbiferous: flowers white to rose-color, 2 to 4 lines long; segments thin and lax in fruit, ovate- to narrowly lanceolate, obtusish or acute, a third longer than the stamens. — *A. Mobilense* and *Drummondii*, Regel, Monogr. All. 112 and 121. *A. reticulatum*, var. γ, Watson, King's Rep. 5. 486. From North Carolina and Florida to Arkansas and New Mexico.

9. A. NUTTALLII. Bulb usually smaller, very fibrous: scape low (4 to 6 inches high): pedicels shorter (4 to 6 lines) and usually rather stouter: perianth-segments usually broader (3 lines long), acute or acuminate, rose-colored or white, rather rigid in fruit. — *A. mutabile*, β, Watson. From Kansas and Colorado to Texas, New Mexico and Eastern Arizona (n. 3219, Berland.; n. 528, Lindh.; n. 847, Fendl.; n. 195, Hall & Harbour; n. 647, Hall; n. 197, 237, Rothrock).

+– +– Capsule crested: spathe usually 2-valved.

10. A. RETICULATUM, Fraser. Scape 3 to 8 inches high: pedicels usually short (2 to 6 lines long): otherwise closely resembling *A. mutabile*. — Hook. Fl. Bor.-Am. 2. 184, t. 195. *A. stellatum*, var., Sims, Bot. Mag. t. 1840. *A. angulosum*, Pursh. From the Saskatchewan to New Mexico and N. Arizona.

11. A. GEYERI. Taller and stouter (a foot high): pedicels 6 to 12 lines long: flowers rose-colored, 4 lines long, the segments broad,

acute or acuminate, strongly nerved and rigid in fruit. — *A. reticulatum*, var. β, Watson, King's Rep. 5. 486. Idaho to Washington Territory and Oregon (n. 226, Geyer; n. 546, Hall & Harbour; n. 386, Howell; Spalding; Wyeth).

* * Bulb-coats not fibrous; some of the outer membranous coats in most species marked by a more or less distinct peculiar reticulate venation: leaves several (2 to 4), shorter than or about equalling the scape: spathe 2-valved, except in n. 21: stamens and style exserted only in n. 20 and 21.

+- Ovary not crested or obscurely 3-crested: perianth-segments not serrulate.

++ Scape usually tall (a foot high or more).

12. A. SCAPOSUM, Benth. Outer bulb-scales dark, with coarse more or less regular vertically oblong rectilinear reticulation: umbel loose, rather few-flowered: perianth-segments white with red midvein, lanceolate, acuminate, 3 or 4 lines long. — Watson, King's Rep. 5. 487, t. 38, f. 10, 11. W. Texas to S. Arizona and Mexico. This is probably identical with the older *A. Kunthii*, Don (*Schœnoprasum lineare*, HBK.)

++ ++ Scape low.

13. A. DOUGLASII, Hook. Reticulation of bulb-coats not detected: scape 8 or 10 inches high: flowers pale rose-color, 3 or 4 lines long; segments lanceolate, acuminate, scarcely exceeding the stamens and style: ovary not at all crested. — Oregon ("Blue Mountains, subalpine hill near Kettle Falls," Douglas). A very obscure species, not identified in recent collections. The figure and description in Hook. Fl. Bor.-Am. refer, with the exception of the scape and the details of the flower, to his var. β, i. e. to *A. Tolmiei*, Baker.

14. A. MADIDUM. Bulbs white, bulbiferous at base, without reticulation: leaves 2, thick and channelled, 1½ to 3 lines broad: scape stout, angled, 4 to 8 inches high: flowers usually many, on pedicels 4 to 6 lines long, white or nearly so, 4 lines long; segments ovate-oblong, acute, a little exceeding the stamens: cells of the ovary with two fleshy ridges at the summit. — Union County, Oregon; W. C. Cusick, n. 382. In small streams or wet places in high ground.

15. A. CUSICKII. Reticulation of bulb-coats not detected: leaves 2, flat, somewhat falcate, 3 lines wide: scape 3 or 4 inches high: flowers rather numerous, on pedicels 6 to 8 lines long, nearly white, 4 or 5 lines long; segments lanceolate, broadly acuminate, nearly twice longer than the stamens and style: ovary-cells shortly apiculate. — Union County, Oregon; W. C. Cusick, n. 179.

16. A. COLLINUM, Dougl. in herb. Known to me only from scanty flowers from Kew Herb. Perianth-segments ovate-lanceolate, acute,

4 lines long, twice longer than the slender stamens and style: capsule very obscurely ridged toward the summit. — "Abundant on the Blue Mountains," Oregon.

17. A. SCILLOIDES, Dougl. in herb. An equally obscure species. Perianth-segments oblong-lanceolate, obtuse, 3 lines long, a half longer than the stamens: ovary not at all crested. — "Priest's Rapids, Columbia River."

++ Ovary rather obscurely crested: scapes low (4 to 10 inches): perianth-segments (at least the inner ones) serrulate.

18. A. ACUMINATUM, Hook. Outer bulb-coats with a distinct coarse quadrate to hexagonal reticulation: pedicels (12 to 30) 6 to 12 lines long: flowers deep rose-color, 4 to 7 lines long; segments lanceolate, with acuminate recurved tips, rigid in fruit, a third longer than the stamens, the inner ones undulate-serrulate: filaments slightly dilated below. — Fl. Bor.-Am. 2. 184, t. 196; Watson, King's Rep. 5. 352, t. 37, f. 6. *A. Murrayanum*, Regel, Gartenfl. 23. 200, t. 770. From Washington Territory to Northern California, Nevada and Utah. *A. Elwesii*, Regel, Pl. Nov. fasc. 5. 50, is probably a form of this species with more obtuse perianth-segments.

19. A. BOLANDERI. Bulb or coated corm propagating by one or two very short lateral offshoots, the coats with a delicate close undulate-serrate reticulation: pedicels 5 to 15: flowers rose-colored or pinkish, 4 or 5 lines long, the segments very narrowly acuminate, nearly straight, twice longer than the stamens and style, the inner ones strongly serrulate: filaments narrowly filiform, adnate to the middle. — Humboldt County, California (n. 6556, Bolander; n. 1011, Kellogg & Harford; Rattan).

+++ Ovary distinctly 6-crested (obscurely so in n. 27, 28): perianth-segments not serrulate, mostly rose-colored.

* Scapes often rather tall.

20. A. STELLATUM, Fraser. Outer bulb-coats reddish, with a very close linear longitudinal reticulation: scape 6 to 18 inches high: umbel few–many-flowered; pedicels 4 to 9 lines long: perianth-segments 2 or 3 lines long, broad, acute: stamens and style exserted: capsule prominently crested. — Ker, Bot. Mag. t. 1576; Hook. Fl. Bor.-Am. 2. 184, t. 194. From the Saskatchewan to Wyoming.

21. A. SANBORNII, Wood. Outer bulb-scales white, some with a very minute irregular reticulation: scape usually a foot or two high: spathe 4-valved: umbel usually densely many-flowered, the pedicels 3 to 8 lines long: perianth-segments 2½ or 3 lines long, ovate-lanceo-

late, thin and lax in fruit: stamens and style exserted: capsule very thin.—Proc. Philad. Acad. 1868, 171; Watson, l. c. 486, t. 37, f. 7. Sierra Nevada (Yuba to Mariposa Counties).

22. A. ATTENUIFOLIUM, Kellogg. Reticulation delicate, horizontally sinuate or serrate, the vertical lines also minutely sinuous: leaves channelled: scape slender (6 to 15 inches high), leafy below: spathe-valves short and abruptly acute: umbel usually dense: perianth-segments 3 or 4 lines long, oblong-lanceolate, acuminate, lax and thin in fruit, white or nearly so.—Proc. Calif. Acad. 2. 110, f. 34; Watson, l. c., t. 37, f. 8, 9. *A. reticulatum*, Benth. Pl. Hartw. 339. *A. amplectens*, Torrey, Pacif. R. Rep. 4. 148. *A. occidentale*, Gray, Proc. Amer. Acad. 7. 390. Sierra Nevada and Coast Ranges, from Mariposa County and San Francisco to Oregon.

↔ ↔ Scapes low: flowers rose-colored.

= Filaments more or less deltoid above the united discoid adnate base.

23. A. SERRATUM, Watson. Resembling *A. acuminatum*; bulb-coats readily fissile along the lines of the fine distinct horizontally serrate reticulation: leaves very narrow: spathe-valves narrowly acuminate: perianth-segments 4 to 6 lines long, deep rose-color, broadly ovate-lanceolate, acute or somewhat acuminate, nearly straight and rather rigid, the inner very rarely serrulate: filaments all with a narrowly deltoid base above the very short disk: crests very narrow, central.—King's Rep. 5. 487, t. 37, f. 4, 5 (reticulation). Coast Ranges (San Diego to Marin County) and foot-hills of the Sierra Nevada.

24. A. BISCEPTRUM, Watson. Bulbs light-colored; reticulation indistinct, somewhat quadrilateral, the cells under a strong power showing an exceedingly sinuous outline especially on the vertical lines: leaves often 2 or 3 lines broad: scapes frequently in pairs: flowers few to many, rose-color, 3 or 4 lines long; segments oblong-lanceolate, acuminate, slightly exceeding the stamens: the alternate filaments with a broad deltoid adnate base: crests thin, conspicuous.—King's Rep. t. 37, f. 1–3 (the figure of the flower faulty as respects the base of the filaments). Sierra Nevada (Mono Lake and northward) and mountains eastward to Utah.

25. A. PALMERI, Watson. Habit of the last: bulb-coats with a distinct somewhat quadilateral reticulation, the outline of the cells very minutely sinuous: scape always solitary: perianth-segments 3 to 5 lines long, ovate-lanceolate, acuminate: filaments and crests nearly as in the last.—King's Rep. 5. 487, t. 37, f. 10, 11. S. Utah to E. Arizona and New Mexico.

26. A. BIGELOVII, Watson. Bulb-coats very dark; reticulation distinct, of nearly regular vertically oblong cells: scape 3 to 6 inches high: flowers rather few, on stout pedicels 4 to 8 lines long, tinged with deep rose-color; segments oblong-lanceolate, acute, 4 to 6 lines long: filaments all with a rather narrowly deltoid base: crests conspicuous. — King's Rep. 5. 487, t. 38, f. 8, 9. Arizona (n. 532, Palmer) and New Mexico.

27. A. LACUNOSUM. Bulb-coats light-colored, thick and distinctly pitted by the quadrate or transversely oblong reticulation, the outlines very minutely sinuous: scape 3 to 6 inches high: flowers usually few (5 to 20), on pedicels 3 to 5 lines long; segments 3 or 4 lines long, oblong-lanceolate, acuminate, a little longer than the filaments, which are all narrowly deltoid at base: cells of the ovary with an obtuse thickened ridge toward the top on each side. — Coast Ranges (Santa Clara County, on Mariposa Peak; n. 1284, Brewer).

28. A. NEVII. Bulb-coats white or reddish, thin, with compressed transversely oblong reticulation (as in *A. tribracteatum*), the cell-outline not at all sinuous: scape slender, 6 or 8 inches high: pedicels rather few, slender, 4 to 6 lines long: perianth-segments light rose-color, lanceolate, acuminate, 3 lines long, scarcely exceeding the stamens and style: cells of the ovary with a thick short crest on each side near the summit. — Oregon (Hood River; Rev. R. D. Nevius).

= = Filaments filiform above the obscurely and obtusely lobed disk.

29. A. CAMPANULATUM. Bulb-coats not known: scape 4 to 6 inches high: umbel somewhat nodding, many-flowered, the slender pedicels 4 to 15 lines long: flowers somewhat campanulate, the segments broadly ovate-lanceolate, acute or abruptly and shortly acuminate, 4 lines long, a third longer than the very slender stamens and style: capsule prominently crested. — Sierra Nevada (Mariposa to Plumas Counties; n. 4943, Bolander; Mrs. M. E. P. Ames).

30. A. BIDWELLIÆ. Reticulation of bulb-coats not known: scape 2 or 3 inches high: umbel rather few-flowered, the pedicels a half-inch long: perianth-segments narrowly lanceolate, acuminate, 2½ or 3 lines long, scarcely exceeding the stamens and style: crests conspicuous. — Sierra Nevada (above Chico, Mrs. J. Bidwell, May, 1878).

* * * Bulb-coats not fibrous: leaf solitary, narrowly linear or filiform, equalling or somewhat exceeding the low scape (2 to 5 inches): capsule prominently 6-crested: stamens and style included.

← Stigma 3-cleft with linear lobes: leaf revolute-filiform: scape very slender.

31. A. PARRYI. Bulb-coats reddish-brown, without reticulation: scape 3 to 6 inches high: spathe-valves 2 or 3, abruptly setaceous-

acuminate: pedicels (12 to 30) 4 to 8 lines long: perianth-segments rose-colored, lanceolate, acuminate, 3 or 4 lines long, a third longer than the stamens: crests emarginate or erose. — Coast Ranges (San Bernardino County, Dr. C. C. Parry, n. 390, 1876).

32. A. FIMBRIATUM. Bulb unknown: scape 3 inches high: pedicels 3 or 4 lines long: flowers deep rose-color, 5 lines long; segments lanceolate, acuminate, nearly a half longer than the stamens and style: crests fimbriate. — S. California (on the Mohave River; Dr. E. Palmer, 1876).

+ + Stigma entire: leaf flat: scape stout, 1 to 3 inches high.

33. A. CRISTATUM. Bulb-coats brownish, some with very faint quadrangular reticulation: spathe-valves more acuminate: pedicels 3 or 4 lines long: perianth light rose-color, 5 lines long; segments lanceolate, acuminate, nearly twice longer than the stamens and style: crests very long, acute, somewhat glandular-toothed. — S. Utah (St. George; Dr. E. Palmer, n. 454, 1877).

34. A. NEVADENSE, Watson. Bulb-coats light-colored, with evident close very much distorted reticulation: spathe-valves acuminate: pedicels half an inch long: perianth white or pinkish, 4 lines long; segments lanceolate, acute or shortly acuminate, little exceeding the stamens and style: crests acutish or obliquely truncate, entire or nearly so. — King's Rep. 5. 351, t. 38, f. 1–3. N. Nevada to S. Utah.

35. A. ATRORUBENS, Watson. Reticulation of bulb-coats not detected: pedicels 5 to 7 lines long: spathe-valves 3, long-acuminate: perianth reddish-purple, 5 or 6 lines long; segments lanceolate, acuminate, little exceeding the very slender and slightly united stamens: crests acute, laciniately toothed. — King's Rep. 5. 352, t. 38, f. 4, 5.

* * * * Leaves 1 to several, linear, greatly exceeding the very short scape: capsule not crested, or very obscurely so.

36. A. TRIBRACTEATUM, Torrey. Bulb-coats thin, with distinct compressed transversely oblong reticulation: leaves 3 or 4 inches long, ½ to 3 lines broad: scape an inch or two high: spathe-valves 3, long-acuminate: pedicels slender, 2 or 3 lines long: perianth pinkish with dark midveins, 3 lines long; segments narrowly oblong-lanceolate, acutish, not gibbous at base, a little longer than the stamens. — Pacif. R. Rep. 4. 148; Watson, l. c. 353, t. 38, f. 6, 7. Sierra Nevada, to 10,000 feet altitude (Mono to Nevada Counties; n. 1799, Brewer).

37. A. PARVUM, Kellogg. Resembling the last: bulb-coats without reticulation: scape scarcely rising above ground: spathe-valves 2,

short, abruptly acute: pedicels stouter: perianth-segments more obtuse, broader, 3 or 4 lines long. — Proc. Calif. Acad. 3. 54, f. 13. *A. tribracteatum*, var. *Andersoni*, Watson, l. c. 353. East base of Sierra Nevada (Carson City to Plumas County).

38. A. MACRUM. Bulb-coats without reticulation: leaves more distinctly sheathing: scape an inch or two high: spathe-valves 2, abruptly acute: umbel more spreading; pedicels slender, 2 or 3 lines long: perianth white or pinkish, 2 or 3 lines long; segments narrowly lanceolate, acuminate, scarcely exceeding the stamens and style: cells of the ovary bordered above by a thick obtuse ridge. — Union County, Oregon, on rocky hills; W. C. Cusick, n. 40, 1877.

§ 3. Bulbs ovate, not rhizomatous, the membranous coats mostly without reticulation: leaves 2, broadly linear, flat and falcate, thick: scape stout, much compressed and 2-winged, low and mostly shorter than the leaves.

* Spathe 2-valved: stamens included: ovary mostly crested.

39. A. FALCIFOLIUM, Hook. & Arn. Scape 2 or 3 inches high: flowers rose-colored, 4 to 6 lines long; segments lanceolate, attenuate and spreading above, minutely glandular-serrate, nearly twice longer than the stamens and style: capsule acute with 3 short narrow central crests. — Bot. Beechey, 400; Watson, l. c. 488, t. 36, f. 7, 8. Coast Ranges (Sonoma to Humboldt Counties).

40. A. BREWERI. Flowers deep rose-color, 5 or 6 lines long; segments lanceolate, acute, nearly erect, not serrulate, a third longer than the stamens and style: ovary and capsule with a thick slightly lobed crest at the apex of each cell. — Summit of Mount Diablo, California; n. 1060, Brewer.

41. A. ANCEPS, Kellogg. Bulb-coats sometimes with minute transversely oblong reticulation: pedicels very slender, 6 to 9 lines long: flowers nearly white with purplish midveins, 3 or 4 lines long; segments very narrowly lanceolate, acuminate, lax, scarcely gibbous at base, little exceeding the stamens and style: capsule-cells with two broad obtuse crests. — Proc. Calif. Acad. 2. 109, f. 32; Watson, l. c. 352, t. 36, f. 4–6 (faulty in showing the capsule without crests). East base of the Sierra Nevada (Carson City to Modoc County); Oregon (Columbia Valley; J. Howell).

42. A. PLEIANTHUM. Scape 4 or 5 inches high: flowers numerous, apparently white, 4 or 5 lines long, on rather stout pedicels 6 to 10 lines long; segments lanceolate, acuminate, gibbous at base, nearly twice longer than the stamens: ovary and capsule prominently 6-crested. — Blue Mountains, Oregon (John Day Valley), and S. Idaho; Rev. R. D. Nevius.

43. A. Tolmiei, Baker. Scape 2 to 4 inches high: pedicels (20 to 30) slender, 4 to 6 lines long: flowers light rose-color with darker midvein, 4 lines long; segments lanceolate, acute, gibbous at base, a half longer than the stamens: ovary very obscurely crested. — Bot. Mag. under t. 6227. *A. Douglasii*, var. β, Hook. Fl. Bor.-Am. 2. 185, & t. 197 mainly. *A. tribracteatum*, Watson, l. c. 353, in part. S. Idaho (Snake County, Tolmie) and Utah (Parley's Park in the Wahsatch Mountains, Watson).

44. A. Lemmoni. Scape 6 inches high: leaves less falcate: flowers rather numerous, pale rose-color without darker midveins, 4 lines long, on pedicels 6 to 8 lines long; segments ovate-lanceolate, acuminate, gibbous, a little longer than the stamens: ovary-cells with a broad obscure crest on each side. — Sierra Nevada (Sierra County, J. G. Lemmon, 1874).

* * Spathe 3–5-valved: stamens exserted: ovary not crested.

45. A. platycaule. Scape 3 to 5 inches high and 2 to 4 lines broad: leaves 6 to 12 lines broad: spathe-valves acuminate: pedicels very numerous, an inch long or less: flowers rose-colored, 4 to 7 lines long; segments lanceolate, very narrowly long-acuminate. — *A. anceps*, Baker, Bot. Mag. t. 6227. Sierra Nevada (high valleys, Placer to Plumas Counties).

§ 4. Bulb an ovate coated corm, propagating by an offshoot from the lower part of the tall terete scape: leaves several, narrow, flat: spathe 2-valved: capsule not crested.

46. A. unifolium, Kellogg. Bulb deep-seated, white, the somewhat chartaceous coat with a close contorted reticulation: scape stout, a foot or two high: flowers (10 to 30) bright rose-color, 5 to 7 lines long, on pedicels an inch long or more; segments ovate-lanceolate, acute or subacuminate, exceeding the stamens and style. — Proc. Calif. Acad. 2. 112, f. 35; Watson, l. c. 486, t. 36, f. 9, 10; Baker, Bot. Mag. t. 6320. Coast Ranges (Mendocino County to San Diego).

Introduced Species, etc.

A. vineale, Linn., is frequent in the Atlantic States, and is often mistaken for *A. Canadense*. It may be readily known by its leafy stem, terete leaves, and cuspidate filaments.

A. Carolinianum, Red., is referred by Regel to *A. blandum*, probably correctly. It is not known in America.

A. Macnabianum, Regel (Gartenfl. 1874, 264, t. 770, fig. 2, 3), cultivated from bulbs probably collected in Oregon, cannot be identified from the description in Regel's Monographia Alliorum.

A. GLANDULOSUM, Link & Otto, is a species of Central and Northern Mexico, with dark purple flowers on slender pedicels; ovary acutish, but not crested; bulbs small, globose, the white coats without reticulation, propagating by a scaly offshoot from the base. The material at hand is too scanty for a satisfactory definition of the few doubtful Mexican species.

2. NOTHOSCORDUM, Kunth.

1. N. STRIATUM, Kunth. Bulb small, often bulbiferous at base: leaves a line or two broad: scape a foot high or often much less: flowers few, 4 to 6 lines long, on slender pedicels: capsule 2 lines long. — Baker, Saund. Ref. Bot. t. 304. *Ornithogalum bivalve*, Linn.? *Allium ornithogaloides*, Walt. *A. striatum*, Jacq. Icon. t. 366; Sims, Bot. Mag. t. 1035 and 1524. *A. ochroleucum*, Nutt. Fl. Ark. 156. *Pseudoscordum striatum*, Torr. & Gray, Pacif. R. Rep. 2. 176. Virginia to Nebraska and southward to Florida, New Mexico and Mexico. The synonymy of the genus is much confused.

3. MUILLA.

1. M. MARITIMA. Corm small, with fibro-membranous coats: leaves scabrous, a line wide or less: scape scabrous, very slender, 2 to 6 inches high or rarely more, with 4 to 6 linear bracts: pedicels (5 to 15) an inch long or less: perianth subrotate, the segments 2 or 3 lines long: anthers very small: capsule 3 lines long, with usually 3 seeds (10 ovules) in each cell. — *Hesperoscordium* (?) *maritimum*, Torr. Pacif. R. Rep. 4. 148. *Allium*, Benth. Pl. Hartw. 339; Regel; Wood; etc. *Milla*, Watson, King's Rep. 5. 354. *Nothoscordum*, Hook. f. Bot. Mag. under t. 5896. California (Marin County to Monterey) and W. Nevada, in saline localities.

4. BLOOMERIA, Kellogg.

1. B. AUREA, Kell. Corm small, at length fibrous-coated: leaves 3 to 6 lines broad: scape scabrous, 6 to 18 inches high: flowers numerous, on slender pedicels, subrotate, the segments 4 to 6 lines long: appendages of the filaments nearly a line long, with a terminal cusp of variable length, minutely papillose. — Proc. Calif. Acad. 2. 11. *Allium croceum*, Torr. Bot. Mex. Bound. 218. *Nothoscordum aureum*, Hook. f. Bot. Mag. t. 5896. S. California (Monterey to San Diego Counties).

5. BRODLÆA, Smith.

• Stamens in one row on the throat; anthers basifixed: purplish perianth mostly broadly funnel-form, the tube shorter than the limb. — § EUBRODLÆA.

+– Stamens 3, opposite to the inner segments and alternate with as many staminodia: segments 2 or 3 times longer than the tube.

++ Pedicels (usually few) more or less elongated.

1. B. GRANDIFLORA, Smith. Leaves a line broad, subterete: scape 4 to 10 inches high: flowers an inch long: staminodia entire, obtuse, about equalling the linear anthers: filaments 1½ lines long or more: capsule oblong, narrowed at base, attenuate above; cells 6–8-seeded: seeds a line long. — Lindl. Bot. Reg. t. 1183; Hook. Bot. Mag. t. 2877; Baker, Journ. Linn. Soc. 11. 376, in part. *Hookera coronaria*, Salisb. Parad. t. 98. From the Mohave River to British Columbia.

Var. (?) MAJOR, Benth. Leaves flattened, 1 to 3 lines broad: scape stouter, a foot or two high, often scabrous: pedicels more numerous (6 to 20) and longer (1 to 4 inches): capsules usually with a broader base, and seeds 2 lines long. — Pl. Hartw. 339. *B. Californica*, Lindl. Trans. Hort. Soc. 4. 84, fig.

2. B. MINOR. Scape very slender, 3 to 6 inches high: flowers a half to one inch long: staminodia broad and usually emarginate, longer than the oblong anthers: capsule obovate, acute, 3 lines long; cells 3-seeded.—*B. grandiflora*, var. *minor*, Benth. Pl. Hartw. 340. California to Oregon.

3. B. TERRESTRIS, Kellogg. Leaves nearly terete: scape very short: pedicels very slender, 3 or 4 inches long: flowers 8 to 10 lines long: staminodia emarginate, yellow, exceeding the oblong sagittate anthers: capsule acute at base, a half-inch long; cells 6–8-seeded. — Proc. Calif. Acad. 2. 6. *B. grandiflora*, var. *macropoda*, Torr. Pacif. R. Rep. 4. 149. *B. Torreyi*, Wood, Proc. Philad. Acad. 1868, 172. Monterey to Mendocino County.

++ ++ Flowers subcapitate.

4. B. CONGESTA, Smith. Corm often deep-seated: scape 2 to 4 feet high, smooth: umbel often produced into a short dense raceme: flowers about 9 lines long: staminodia deeply cleft, exceeding the nearly sessile emarginate anthers: capsule ovate: seeds usually solitary, 2 lines long. — Trans. Linn. Soc. 10. 3, t. 1. *Dichelostemma*, Kunth, Enum. 4. 470. San Francisco to Washington Territory.

5. B. MULTIFLORA, Benth. Corm less deeply seated: scape 1 or 2 feet high, somewhat scabrous: umbel not produced: staminodia broad, entire, obtuse, about equalling the anthers: seeds several in each cell:

otherwise as the last. — Pl. Hartw. 339; Hook. f. Bot. Mag. t. 5989. *B. parviflora*, Torr. & Gray, Pacif. R. Rep. 2. 125. *B. grandiflora*, var. *brachypoda*, Torr., same, 4. 149. Sacramento Valley to Oregon and in the Sierra Nevada.

+ + Stamens 6, those opposite the inner perianth-segments with their short filaments conspicuously wing-appendaged: segments little longer than the tube: flowers subcapitate.

6. B. CAPITATA, Benth. Scape usually 1 or 2 feet high: flowers 6 to 10 lines long: outer filaments dilated at base; inner anthers linear, little shorter than the oblong-lanceolate wings: capsule ovate, 3 lines long; cells several-seeded. — Pl. Hartw. 339. *Hookera pulchella*, Salisb. Parad. t. 117? *Dichelostemma capitata*, Wood, l. c. 173. *Milla capitata*, Baker, l. c. 381. California to Utah.

* * Stamens in 2 rows (except in n. 8), with more or less distinctly versatile anthers and naked filaments: capsule stipitate: perianth-segments equalling or shorter than the mostly narrow tube. — § SEUBERTIA.

+ Perianth broadly funnel-form: flowers subcapitate.

7. B. DOUGLASII. Scape 1 or 2 feet high: flowers few or many, blue, 8 to 12 lines long: anthers a line long, the lower on the throat, the upper on the inner perianth-segments; filaments short. — *Triteleia grandiflora*, Lindl.; Hook. Fl. Bor.-Am. 2. 186, t. 198, B. *Brodiæa grandiflora*, Torr. in Stansb. Rep. 397. *Milla grandiflora*, Baker, l. c. Washington Territory and Oregon to Wyoming and Utah.

+ + Perianth more or less attenuate at base: umbel open.

++ Flowers blue or purplish; rarely white.

8. B. BRIDGESII. Scape a foot high or more; flowers 12 to 15 lines long, the very narrow tube exceeding the segments: filaments deltoid, in one row on the throat; anthers linear, 2 lines long: capsule ovate, shorter than the stipe, beaked by the very slender style: seeds 2 or 3 in each cell. — Central California (foothills of the Sierra Nevada; Bridges, n. 338; and others).

9. B. LAXA. Scapes 6 inches to 2 feet high, smooth or scabrous: flowers few to many, 12 to 20 lines long, the very narrow tube equalling or exceeding the segments: filaments very slender, short or elongated, the upper on the throat opposite the inner segments: capsule oblong, long-stipitate; style rather short: seeds several. — *Triteleia laxa*, Benth. Trans. Hort. Soc. 1. 413, t. 15, f. 2; Lindl. Bot. Reg. t. 1685. *Seubertia*, Kunth. *Milla*, Baker. Coast Ranges, from San Francisco to Humboldt County.

10. B. PEDUNCULARIS. Scape 1 or 2 feet high, smooth: flowers smaller (6 to 9 lines long), on very slender pedicels, the segments a

little longer than the turbinate tube: lower anthers sessile, the upper on short filaments: capsule on a stipe 1 or 2 lines long. — *Triteleia*, Lindl. Bot. Reg. under t. 1685. *Milla*, Baker. Coast Ranges of Central California.

↔ ↔ Flowers yellow, with brown nerves.

11. B. CROCEA. Leaves 2 to 6 lines broad: scape a foot high or more, smooth: bracts linear, elongated: flowers 7 to 9 lines long, on pedicels 2 inches long or less, the segments a little exceeding the turbinate tube: anthers small (a line long), on short slightly dilated filaments: ovary pubescent on the angles: capsule obovate, abruptly narrowed above, shortly stipitate; cells 4-seeded. — *Seubertia*, Wood, l. c. 171. *Milla*, Baker. Siskiyou County.

12. B. GRACILIS. Leaf solitary, 1 to 3 lines broad: scape 2 to 4 inches high, purplish, scabrous: bracts short, lanceolate: flowers 5 to 7 lines long, on pedicels 6 to 12 lines long, the segments about equalling the narrow tube: anthers very small, on very slender elongated filaments: capsule ovate-oblong, attenuate above, on a slender stipe; cells 2-seeded. — On Spanish Peak, Plumas County; collected by Mrs. R. M. Austin.

* * * Stamens in one row, with deltoid or wing-dilated filaments and versatile anthers: capsule stipitate: perianth-segments twice longer than the turbinate tube. — § CALLIPRORA. [See p. 301.]

13. B. IXIOIDES. Scape 3 inches to 2 feet high, usually scabrous: flowers few to many, on pedicels 1 to 4 inches long, yellow more or less tinged with purple or nearly white (the brown midvein often double or triple), 5 to 10 lines long: filaments winged their whole length, bicuspidate above; anthers small: capsule ovate-oblong; stipe 2 or 3 lines long. — *Ornithogalum ixioides*, Ait. f. Hort. Kew. 2. 257. *Calliprora lutea*, Lindl. Bot. Reg. t. 1590; Hook. Bot. Mag. t. 3588. *Themis ixioides*, Salisb. *Calliprora aurantea*, Kellogg, Proc. Calif. Acad. 2. 20. *Milla ixioides*, Baker. From Santa Barbara to Oregon.

14. B. LACTEA. Scape usually 1 or 2 feet high, smooth or scabrous: flowers few to many, on slender pedicels 2 inches long or less, white with green midvein or sometimes purplish, 4 or 5 lines long: filaments deltoid, a line long; anthers small: capsule subglobose; stipe a line or two long. — *B. grandiflora*, Pursh. *Hesperoscordum lacteum* and *hyacinthinum*, Lindl. Bot. Reg. t. 1639. *Allium lacteum*, Benth. Pl. Hartw. 339. *H. Lewisii*, Hook. Fl. Bor.-Am. 2. 185, t. 198. *Veatchia crystallina*, Kellogg, l. c. 2. 11. *Milla hyacinthina*, Baker. *Allium Tilingi*, Regel, All. Monogr. 124. Coast Ranges and Sierra Nevada from Monterey to British Columbia.

Var. LILACINA. A stout form, with large flowers, from white becoming more or less tinged with lilac. — Mendocino and Humboldt Counties.

6. STROPHOLIRION, Torr.

1. S. CALIFORNICUM, Torr. Scape lax or often twining, 2 to 12 feet long, scabrous: pedicels (15 to 30) an inch long or less: flowers 5 or 6 lines long, with oblong-lanceolate segments: anthers equalling the narrrow emarginate white staminodia and the lanceolate acute wings of the filaments (2 lines long): capsule shorter than the perianth. — Pacif. R. Rep. 4. 149, t. 23. *Rupalleya volubilis*, Morière, Bull. Soc. Norm. 8. 313, t. *Dichelostemma Californica*, Wood, Proc. Acad. Philad. 1868, 173. *Brodiæa volubilis*, Baker, Journ. Linn. Soc. 11. 177; Hook. f. Bot. Mag. t. 6123. Foothills of the Sierra Nevada (Mariposa County and northward).

7. BREVOORTIA, Wood.

1. B. COCCINEA. Scape erect, 1 to 3 feet high, with reddish bracts: pedicels (6 to 15) an inch long or less: flowers 12 to 16 lines long, with ovate segments 2 or 3 lines in length: anthers equalling the limb; staminodia a half shorter, yellow: capsule as long as the perianth, on a stipe 2 or 3 lines long. — *B. Ida-Maia*, Wood, Proc. Acad. Philad. 1867, 82. *Brodiæa coccinea*, Gray, Proc. Amer. Acad. 7. 389; Baker, Journ. Linn. Soc. 11. 378; Hook. f. Bot. Mag. t. 5857. N. California (Humboldt to Shasta Counties).

8. ANDROSTEPHIUM, Torr.

1. A. VIOLACEUM, Torr. Scape 2 to 6 inches high: flowers 8 to 12 lines long or more, usually exceeding the stout pedicels; tube nearly as long as the limb: crown scarcely shorter than the limb, the lobes exceeding the anthers. — Bot. Mex. Bound. 218. *Milla cærulea*, Scheele, Linnæa, 25. 260. W. Kansas to Texas.

2. A. BREVIFLORUM, Watson. Scape usually stouter, 3 to 12 inches high: flowers half an inch long, mostly shorter than the pedicels, and the tube much shorter than the limb: lobes of the crown shorter than the anthers. — Amer. Naturalist, 7. 303. S. Utah to S. E. California.

The Mexican genus BESSERA, of a single species (B. ELEGANS, Schult.), is closely allied to *Androstephium*; flowers bright scarlet, the more spreading segments closely 3-nerved; the elongated filaments and style exserted.

9. MILLA, Cav.

1. M. BIFLORA, Cav. Corm small, membranous-coated: leaves subterete, very rough: scape smooth, 2 to 12 inches high, bearing 1 to 5 nearly equal elongated pedicels (3 to 6 inches long): perianth 1½ to 2 inches long, the broadly oblong-lanceolate segments (the inner narrower) about twice longer than the tube.—Icon. 2. 76, t. 196; Lindl. Bot. Reg. t. 1555. *Diphalangium graminifolium*, Schauer, Linnæa, 19. 702. From S. Arizona and New Mexico to Central Mexico.

10. LEUCOCRINUM, Nutt.

1. L. MONTANUM, Nutt. Leaves several, rather thick, 1 to 3 lines broad: flowers (4 to 8) on pedicels ½ to 1½ inches long, the very slender tube an inch or two long: capsule truncate, 3 or 4 lines long, with 4 to 6 seeds in each cell.—Gray, Ann. N. Y. Lyc. 4. 110; Watson, King's Rep. 5. 349, t. 36, f. 1–3. *Weldenia*, Endl. Gen. Pl. 1358. Colorado to N. California, in sandy valleys.

The Mexican WELDENIA CANDIDA is known only from the description and figure by Schult. f. (in Regensb. Flora (1829), 12. 1, t. 1, and Syst. 7. 1136), based upon a single imperfect specimen collected by Karwinsky in the mountains near Toluca ("Nevada de Toluca"). It is represented as differing from *Leucocrinum* mainly in its broader and short leaves, perianth-segments only three, and anthers extrorse.

11. CAMASSIA, Lindl.

1. C. ESCULENTA, Lindl. Scape stout, a foot or two high: leaves 3 to 8 lines broad: pedicels rather stout, mostly shorter than the usually dark-blue flowers: perianth-segments 7 to 15 lines long, scarcely exceeding the style, a little longer than the stamens: anthers a line or two long: ovules 16 to 18 in each cell: capsule oblong-obovate, somewhat narrowed at base, rather obtusely angled, 6 to 12 lines long.—Bot. Reg. t. 1486; Fl. Serres, t. 275; Baker, Journ. Linn. Soc. 13. 256. *Phalangium Quamash*, Pursh. *Scilla esculenta*, var., Hook. Bot. Mag. t. 2774, the white-flowered form, which is also *Chlorogalum Leichtlinii*, Baker, Gard. Chron. 1874, 689, and *Camassia esculenta*, var. *Leichtlinii*, Baker, Bot. Mag. t. 6287. British Columbia to California and Utah.

2. C. FRASERI, Torr. Pedicels more slender and often exceeding the smaller (4 to 7 lines long) light-blue flowers: ovules 6 to 9 in each cell: capsule very broadly triangular-globose, acutely angled, 3

or 4 lines long. — Pacif. R. Rep. 4. 147 (and 2. 176); Baker, l. c. *Phalangium esculentum*, Nutt. in Fras. Cat. 1813. *Scilla esculenta*, Ker, Bot. Mag. t. 1574. *Anthericum esculentum*, Schultes. *Lemotrys hyacinthina*, Raf. *Scilla Fraseri*, Gray. From Pennsylvania to Iowa and Texas.

Var. ANGUSTA, Torr. l. c. Very slender and the leaves narrow (3 or 4 lines broad): flowers still smaller, 3 or 4 lines long. — *Scilla angusta*, Engelm. & Gray, Pl. Lindh. 29. Louisiana and Arkansas to Texas.

12. HESPERANTHES.

1. H. TORREYI. Roots thick, cylindrical: stem slender, 1 to 3 feet high, naked or with 1 or 2 setaceous leaves; radical leaves several, elongated, smooth, a line or two wide: raceme simple or branched, loosely flowered; pedicels half an inch long or less: flowers yellow with brownish nerves, 5 or 6 lines long: filaments slightly roughened: capsule 6 lines long, the cells 12–16-seeded. — *Echeandia terniflora*, var. (?) *angustifolia*, Torr. Bot. Mex. Bound. 219. *Anthericum Torreyi*, Baker, Journ. Linn. Soc. 15. 317. *Echeandia terniflora*, Rothr. in Wheel. Rep. 6. 269. W. Texas to Arizona.

Mexican Species.

2. H. LEPTOPHYLLA. Roots elongated, thickened below: stem slender, a foot high or more: leaves numerous, short and very narrow, scabrous on the margin: flowers yellowish, 5 lines long; filaments very rough: capsule shorter. — *Echeandia leptophylla*, Benth. Pl. Hartw. 25. *Anthericum*, Baker, l. c.

3. H. STENOCARPA. Stem rather stout, a foot high or more, simple or strictly branched, with 2 or 3 broad leaves: radical leaves several, elongated, smooth, 3 or 4 lines broad: flowers 6 to 8 lines long, on stout erect pedicels: filaments coarsely muricate: capsule 6 lines long, the cells 30–40-seeded. — *Anthericum stenocarpum*, Baker, l. c.

4. H. SCABRELLA. Roots thickened, an inch long: stem 6 to 12 inches high, simple or scarcely branched, puberulent or glabrous, few-flowered: leaves short, glabrous except the scabrous-ciliolate margin, 3 or 4 lines broad: flowers 6 lines long, on stout erect pedicels: filaments slightly muricate: capsule 5 lines long, the cells about 12-seeded. — *Phalangium scabrellum*, Benth. Pl. Hartw. 293. *Anthericum*, Baker, l. c. The other species described by Mr. Baker (*Anthericum flavescens*, Schult., and *A. Skinneri*, Baker), I have not seen.

Echeandia, Ort., is a very similar Mexican genus, distinguished by linear anthers longer than the short filaments and connivent over the ovary. Mr. Baker recognizes one rather variable species, E. terniflora, Ort., which has not been collected within the United States.

13. SCHŒNOLIRION, Torr.

1. S. croceum, Gray. Stem very slender, a foot high: raceme simple, short (1 to 4 inches): bracts ovate, mostly obtuse, purplish: flowers yellow tinged with red; segments narrow, 2½ to 3 lines long: seed nearly 2 lines long. — Amer. Naturalist, 10. 427. *Phalangium croceum*, Michx. *Anthericum croceum* and *Nuttallianum*, Schult. f. Syst. 7. 476. *Amblostima crocea*, and *Oxytria crocea*, Raf. Fl. Tellur. 26. *Ornithogalum* (?) *croceum* and *Nuttallianum*, Kunth, Enum. 4. 371. Georgia to Florida.

2. S. Texanum, Gray, l. c. Resembling the last, but flowers greenish white: bracts narrower, acutish: seed a line long. — *Ornithogalum Texanum*, Scheele, Linnæa, 23. 146. *S. Michauxii*, Torr. Bot. Mex. Bound. 220, excl. syn. and descr. Texas and Louisiana.

3. S. Elliottii, Feay. Stem stouter, 2 feet high, less thickened at base; racemes usually panicled, becoming 2 to 4 inches long: bracts acute or acuminate: flowers white, with oval 5-nerved segments, 2 or 3 lines long: capsule coriaceous, and seed nearly 2 lines long. — Gray, l. c. *Ornithogalum croceum*, Elliott. *Amblostima albiflora* and *latifolia* (?), Raf. l. c. *S. Michauxii*, Torr. l. c., mainly. *Anthericum croceum*, Baker, Journ. Linn. Soc. 15. 297. Georgia and Florida.

14. HASTINGSIA.

1. H. alba. Stem 2 or 3 feet high, often stout: leaves 2 to 6 lines broad: raceme simple or sparingly branched, densely many-flowered (often a foot long): pedicels a line long or less: bracts narrowly acuminate: flowers 2 or 3 lines long, often tinged with green or pink. — *Schœnolirion album*, Durand, Journ. Acad. Philad. 2. 3. 103; Gray, Amer. Naturalist, 10. 552. Northern California (Plumas to Humboldt Counties and northward).

15. CHLOROGALUM, Kunth.

* Perianth-segments narrowly ligulate, spreading widely from the base in the open flower: pedicels nearly equalling the flowers.

1. C. pomeridianum, Kunth. Bulb large, thickly coated with coarse brown fibres: stem and spreading panicle 1 to 3 feet high:

leaves 4 to 10 lines broad: flowers white, purple-veined, 8 to 10 lines long, on spreading pedicels 2 to 9 lines long: capsule 3 lines long. — Torr. Bot. Mex. Bound. t. 60; Baker, Journ. Linn. Soc. 13. 291. *Anthericum*, Ker, Bot. Reg. t. 564. *Scilla*, DC.; Red. Lil. t. 421. *Phalangium*, Don, Sweet's Fl. Gard. 2 ser. t. 381. *Ornithogalum divaricatum*, Lindl. Bot. Reg. 28, t. 28. *C. divaricatum*, Kunth. California (valleys and foothills, from the Upper Sacramento to Tuolumne County and Santa Barbara).

* * Perianth-segments oblong-oblanceolate, spreading from above the base: pedicels very short.

2. C. PARVIFLORUM. Bulb smaller (an inch thick), with dark membranous coats: stem 2 or 3 feet high, with slender divaricate branches: leaves grass-like (2 or 3 lines broad): pedicels rarely a line or two long, mostly shorter than the bracts: flowers pinkish, 3 or 4 lines long: ovary broad and obtuse: capsule smaller (scarcely 2 lines in diameter). — S. California (Cajon Valley, near San Diego; D. Cleveland, 1877).

3. C. ANGUSTIFOLIUM, Kellogg. Resembling the last: flowers white with yellowish-green lines, 3 to 6 lines long, narrow at base; the ovary being oblong-ovate, acutish above, and shortly stipitate. — Proc. Calif. Acad. 2. 105, fig. 30. California (Shasta County, Kellogg; near Yuba, A. Wood).

16. ODONTOSTOMUM, Torr.

1. O. HARTWEGI, Torr. Stem a foot or two high, branching from the ground: corm deep-seated, an inch in diameter: leaves rather short, flat or somewhat undulate, 4 to 6 lines wide: racemes loosely many-flowered; bracts and bractlets very narrow: pedicels usually very slender and exceeding the bracts: flowers 4 to 6 lines long; segments of the limb oblong: style equalling the tube: capsule nearly 2 lines long. — Bot. Mex. Bound. 150, t. 24; Baker, Journ. Linn. Soc. 11. 436. Foothills of the Sierra Nevada (Butte to Amador Counties).

17. CONVALLARIA, Linn.

1. C. MAJALIS, Linn. Leaves broadly elliptic to oblanceolate, exceeding the angular scape: perianth 3 lines long and nearly as broad: berry 3 or 4 lines in diameter. — Alleghanies (Virginia to S. Carolina); apparently identical with the plant of Europe and Asia (or lobes narrower and more acute?).

18. POLYGONATUM, Tourn.

1. P. BIFLORUM, Ell. Stem slender, usually declinate, 1½ to 3 feet high: leaves ovate-lanceolate to lanceolate, mostly narrow at base, 2 to 4 inches long, pubescent beneath: pedicels jointed at or very near the base of the flower, 3 to 6 lines long, naked: flowers 1 or 2 (rarely 3) at each axil, 4 to 6 lines long. — *Convallaria biflora*, Walt. *C. pubescens*, Willd. Hort. Berol. t. 45. *C. canaliculata*, Muhl.; Willd. l. c. *P. angustifolium*, *canaliculatum*, *pubescens*, *multiflorum* and *hirtum*, Pursh. Canada (New Brunswick to Winnipeg Valley) to Florida; wooded hillsides.

2. P. GIGANTEUM, Dietr. Glabrous throughout: stem somewhat curved, 2 to 7 feet high: leaves broadly ovate to lanceolate, usually clasping by a broad base, 3 to 8 inches long: pedicels jointed below (½ to 1 line or more) the base of the flower, ½ to 3 inches long including the common peduncle, frequently with narrow bracts: flowers 1 to 10 or more, 5 to 9 lines long. — Otto, Gartenz. 1835, 222. *Convallaria commutata*, Schult. Syst. 7. 1671. *P. commutatum* and *P. parviflorum*, Dietr. l. c. *P. latifolium*, var. *commutatum*, Baker, Journ. Linn. Soc. 14. 555, chiefly. New England to Lake Winnipeg and the Upper Missouri, and from Virginia to New Mexico; meadows and river-banks. Neither *P. latifolium* nor *P. multiflorum* is American, though the latter is frequent in cultivation; both have the pedicel jointed at the base of the flower.

19. SMILACINA, Desf.

* Flowers on very short pedicels in a terminal racemose panicle: stamens exceeding the small (a line long) oblong-lanceolate segments: ovules collateral.

1. S. RACEMOSA, Desf. More or less pubescent: rootstock stout: stem 1 to 3 feet high, somewhat flexuous: leaves oblong-lanceolate, mostly narrowly acuminate, abruptly short-petioled: style very short: berry reddish, purple-dotted, 3 lines broad, usually 1-seeded: seed whitish, 2 lines in diameter. — Ann. Mus. Par. 9. 51; Torr. Fl. N. York, 2. 298, t. 130. *Convallaria racemosa*, Linn.; Sims, Bot. Mag. t. 899. *Tovaria*, Necker; Baker, Journ. Linn. Soc. 14. 570. *Polygonastrum*, Moench. *Maianthemum*, Link. *S. ciliata*, Desf. l. c., t. 9. New Brunswick to Winnipeg Valley, south to S. Carolina and Arkansas.

2. S. AMPLEXICAULIS, Nutt. Similar: leaves ovate to lanceolate, rarely at all acuminate, mostly sessile and clasping at base: style

longer, nearly equalling the ovary: seed smaller. — Journ. Philad. Acad. 7. 58. *S. racemosa*, var. *amplexicaulis*, Watson, King's Rep. 5. 345. *Tovaria racemosa*, Baker, l. c. in part. British Columbia to California (Monterey) and east to Wyoming and New Mexico.

* * Flowers larger, on solitary pedicels in a simple few-flowered open raceme: stamens included: ovules not collateral.

+ Leaves (7 to 12) sessile: raceme sessile or nearly so: berry blue-black.

3. S. STELLATA, Desf. l. c. Glabrous or pubescent: stem a foot high or less: leaves lanceolate, acutish, sessile and closely clasping, usually ascending and folded: raceme about an inch long: perianth-segments 2 or 3 lines long, exceeding the pedicels: berry 3 lines broad: seeds brown. — *Convallaria stellata*, Linn.; Sims, Bot. Mag. t. 1043. *Tovaria*, Necker; Baker, l. c. 565. *Maianthemum*, Link. *Asteranthemum vulgare*, Kunth. Labrador to E. Oregon and N. E. California, south to Pennsylvania, Iowa and New Mexico: the Norway plant appears to be the same.

4. S. SESSILIFOLIA, Nutt. in herb. Rootstock slender: stem a foot or two high: leaves lanceolate, acuminate, sessile, usually flat and spreading, somewhat puberulent: raceme larger, the pedicels 2 to 7 lines long: flowers often larger: berry 3 to 5 lines in diameter.— *Tovaria sessilifolia*, Baker, l. c. 566. California (Monterey) to British Columbia and east to the Wahsatch; has been usually referred to *S. stellata*.

+ + Leaves (2 to 4) sheathing the low stem: raceme pedunculate: berry red.

5. S. TRIFOLIA, Desf. l. c. Glabrous, 2 to 6 inches high: leaves oblong, narrowed below, acute: pedicels exceeding the flowers, which are 1½ lines long: berry 2 to 3 lines in diameter. — *Convallaria trifolia*, Linn.; Gmel. Fl. Sib. 1. 36, t. 6. *Tovaria*, Necker; Baker, l. c. 565. *Maianthemum*, Raf. *Asteranthemum*, Kunth. Labrador to New England, Michigan and the Saskatchewan; also in E. Siberia.

Species of Mexico, &c.

* Flowers solitary, paniculate: stamens included.

6. S. PANICULATA, Mart. & Gal. Leaves 7 to 9, broadly lanceolate: flowers large, on elongated pedicels in a dense compound corymb. — Central Mexico and Guatemala.

7. S. THYRSOIDEA (*Tovaria*, Baker). Leaves 10 to 15, lanceolate, often narrow, long-acuminate: flowers smaller, on short pedicels in a large open spreading panicle. — Central Mexico.

8. S. NERVULOSA (*Tovaria*, Baker). Leaves 5 or 6: panicle

oblong, small, with few divaricate branches: flowers small (2 lines broad), on very short pedicels: style very short. — Jalapa.

9. S. LAXIFLORA (*Tovaria*, Baker). Leaves 6 to 9: panicle deltoid, with ascending branches: flowers twice larger, on pedicels 3 to 6 lines long: style as long as the ovary. — Guatemala.

* * Flowers mostly fascicled in a simple raceme.

10. S. SCILLOIDES, Mart. & Gal. Leaves 6 or 8, narrowly oblong: raceme straight: flowers small: style as long as the ovary. — Central Mexico.

11. S. FLEXUOSA, Bertol. Leaves 10 or 12, oblong to ovate: raceme very flexuous: flowers large: style twice longer than the ovary. — Guatemala.

20. MAIANTHEMUM, Weber.

1. M. CANADENSE, Desf. Pubescent or glabrous, 3 to 5 inches high: leaves lanceolate to ovate, cordate at base with a narrow sinus, sessile or very shortly petioled: perianth-segments a line long: style slender, as long as the ovary: berry 1½ to 2 lines in diameter: seeds light-colored, scarcely over a line thick. — Ann. Mus. Par. 9. 52; DC. in Red. Lil. t. 216, f. 1. *Smilacina Canadensis*, Pursh; Bart. Fl. N. Am. t. 70. *Convallaria Canadensis*, Poir. *Smilacina bifolia*, var. *Canadensis*, Gray. Labrador to the Saskatchewan, south to Iowa, Illinois and N. Carolina.

2. M. BIFOLIUM, DC. Low and slender, somewhat pubescent: leaves ovate-cordate with a broad sinus, the lower rather abruptly acute and with a petiole ½ to an inch long, the upper more attenuate and petiole shorter: style long and slender: berry 2 lines in diameter, 1–2-seeded: seed brown, a line thick. — Var. (?) DILATATUM, Wood. Stouter (6 to 12 inches high), glabrous: leaves broader, the lower subreniform-cordate with petioles often 2 inches long or more: flowers rather larger: style shorter, stout: berry larger, 2–4-seeded: seed brownish, 1½ lines thick. — Proc. Philad. Acad. 1868, 174. *Smilacina dilatatum*, Nutt. in herb. California (Marin County) to Alaska. Apparently connected with the typical form by var. *Kamschaticum* of Eastern Siberia, with slender style. The present form seems to recur also in Japan.

21. NOLINA, Michx.

* Fruit somewhat inflated, the cells not burst by the ripening seed.

1. N. GEORGIANA, Michx. Stem slender from a thick rhizome, 1 to 3 feet high, including the simple sparingly branched panicle:

leaves flat, shorter than the stem, about a line wide, the cauline small and subfiliform: bracts subtending the branches of the panicle very small: fruit obcordate in outline, 3 lines long, on a pedicel 4 lines long. — Fl. 1. 208; Baker, Journ. Linn. Soc. 13. 292. *Phalangium virgatum*, Poir. in Lam. Dict. 5. 246. S. Carolina to Florida (Tampa Bay and St. Augustine). Specimens from the last locality have thicker fruit, only 2 lines long, on very short pedicels.

2. N. Lindheimeriana. Stem stout, 2 to 6 feet high, from a very short caudex: leaves flat and thin, 2 to 4 lines broad below, 1 to 3 feet long, strongly serrulate; the cauline 6 inches long: panicle simple or sometimes compound, the bracts not conspicuous: fruit very thin, emarginate at both ends (more deeply above), wider than long (5 lines broad), on pedicels about 4 lines long. — *Dasylirion Lindheimerianum*, Scheele, Linnæa, 25. 262. *D. tenuifolium*, Torr. Bot. Mex. Bound. 215. *Beaucarnea Lindheimeriana*, Baker, Trim. Journ. Bot. 10. 328. Texas.

3. N. microcarpa. Stem stout, 6 feet high, from a short caudex: leaves concavo-convex, rather thick and somewhat carinate, 4 to 6 lines broad, very strongly serrulate, fibro-lacerate at the apex: panicle narrow, branched at base; branches slender, a foot long, with ascending branchlets (2 or 3 inches long); bracts small: fruit as in the last but smaller (3 lines broad), on very slender pedicels 2 or 3 lines long: stigmas very short, sessile. — *Dasylirion erumpens*, Rothr. in Wheeler's Rep. 6. 272. S. Arizona (Rock Cañon; Rothrock, n. 278). Resembling *N. erumpens*: only immature fruit known.

4. N. Bigelovii. "Scape 3 feet high": leaves flat, nearly an inch wide above the broad deltoid base, not carinate, 3 or 4 feet long, the margin roughish: panicle compound; branchlets slender, an inch or two long: fruit very thin, 4 or 5 lines in diameter, emarginate at both ends, on very slender pedicels 2 to 4 lines long: seed ovate-oblong, 2 lines long, whitish, slightly reticulated. — *Dasylirion Bigelovii*, Torr. Pacif. R. Rep. 4. 151. *Beaucarnea Bigelovii*, Baker, l. c. 326. W. Arizona. The plant found by Schott in Sonora, referred to this species in Bot. Mex. Bound. 216, is probably distinct, but has not been seen for comparison.

5. N. Parryi. Resembling the last: caudex 3 to 6 feet high: leaves thicker and somewhat concave above, especially toward the stout apex, very strongly serrulate on the margin: branchlets of the panicle and the pedicels stouter: fruit 6 lines in diameter: seed subglobose, the very thin testa finely and irregularly wrinkled. — California (western border of San Bernardino Desert; Parry, 1876).

* * Seed bursting the cell before maturity and remaining exposed.

6. N. Texana. Stems very short, a foot or two high including the panicle, several from a very short caudex: leaves covering the ground, a line or two broad, concavo-convex below, triangular toward the apex, 2 to 4 feet long, roughish on the margins: panicle compound, the main bracts large and foliaceous with dilated bases: capsules 2–3 lines broad before rupture, on pedicels 2 or 3 lines long: seed globose, nearly smooth, 2 lines in diameter. — Texas (Austin to the Nueces; n. 550, 712, Lindheimer; n. 692, Wright; n. 635, Hall). Flowering in March; in fruit in May. Referred to the Mexican *Beaucarnea Hartwegiana* by Baker, l. c.

7. N. erumpens. Stem 2 to 5 feet high, somewhat rough-scabrous: leaves thick, concavo-convex and somewhat carinate, half an inch broad above the base, 2 or 3 feet long, very strongly serrulate: panicle compound, with large dilated bracts; partial panicles pyramidal, 6 inches long, with the lower subdivaricate branchlets 2 or 3 inches long: stigmas linear, distinct, sessile: pedicels 2 lines long or less. — *Dasylirion erumpens*, Torr. Bot. Mex. Bound. 216. *Beaucarnea*, Baker, l. c. 326. Western Texas (between the Rio Pecos and the Rio Grande).

8. N. Palmeri. Stem glabrous: leaves probably flat and broad, very strongly serrulate: panicle compound, 3 feet long and narrow, the partial panicles only 3 inches long or less, and the branchlets an inch long; bracts similar: stigmas upon a short style: fruit 2 lines broad before rupture, on pedicels 2 lines long: seeds globose, with minutely wrinkled testa. — Lower California (Tantillas Mountains; Palmer, 1875).

9. N. humilis. Stems stout, very short (a foot high or less, including the panicle), clustered, from a subterranean rootstock: leaves 2 feet long, 2 to 4 lines broad at base, becoming very narrow, more or less channelled above and usually carinate beneath, triangular toward the apex, very rough on the margin: panicle 4 to 6 inches long, with simple suberect branches, dense: flowers large, the segments 1½ lines long: capsule equalling the pedicel, 3 lines long before rupture, thin-membranous: seed obovate, 3 lines long, with a white smooth thick and subcrustaceous testa. — Among rocks, San Luis Mountains, Mexico; Parry & Palmer (n. 874, 875).

The remaining Mexican species of *Beaucarnea*, described by Mr. Baker, l. c., are doubtless all to be referred to this genus, but are very imperfectly known.

22. DASYLIRION, Zucc.

1. D. Texanum, Scheele. Caudex 2 to 5 feet high, bearing a dense rosette of leaves and a flowering stem 8 or 10 feet long: leaves light-green, 3 or 4 feet long, 4 or 5 lines broad below and attenuate upward, splitting into coarse fibres at the apex, the serrulate margin armed with hooked teeth a line long and 3 to 6 lines apart; the dilated base narrowed gradually into the leaf, entire: panicle 2 or 3 feet long, very narrow; the partial panicles erect or suberect and about 3 inches long, equalling the broad subtending bracts; racemes an inch or two long, ascending: floral bractlets broadly ovate, acute, lacerately toothed, about a line long: perianth a line long: fruit 3 to 3½ lines long, on pedicels a line long, broadly elliptical, the rather narrow wings continued above and adnate to the style (or attenuate apex of the body) its whole length: seed (immature) 1½ lines long, acute at both ends. — Linnæa, 23. 140. *D. graminifolium*, Baker, Trim. Journ. Bot. 10. 297, mainly. W. Texas and Eastern New Mexico.

2. D. Wheeleri, Watson. Similar in size (12 to 14 feet high) and habit: leaves 7 to 9 lines broad, with brown-tipped teeth: racemes longer (2 to 4 inches), flexuous and usually pendent: fruit narrowly obcordate, 4 lines long, on pedicels a line or two long, the wings adnate only to the base of the style and prolonged above it in divergent obtuse lobes a line long: seed 2 lines long, acutish. — Rothrock, Wheeler's Rep. 6. 379. *D. graminifolium*, Rothr. l. c. 6. 272. S. Arizona (Bischoff; Rothrock, n. 329, 655) and southwestern New Mexico (Emory).

Mexican Species.

3. D. Berlandieri. Only the fruiting panicle known. Racemes stout, spreading, 2 inches long: floral bracts equalling or exceeding the pedicels, 2 or 3 lines long, broadly lanceolate, acute, nearly entire: perianth-segments 2 to 2½ lines long: fruit very broadly winged (suborbicular); summits of the wings broad and divergent, the free portion of the style and the stigmas a line long. — N. E. Mexico (Nuevo Leon, Berlandier, n. 3218).

4. D. graminifolium, Zucc. Resembling *D. Texanum;* base of the somewhat shorter glaucous leaves abruptly contracted and spine-toothed above: staminate spikes thicker: body of the fruit less attenuate above and wings free from the style. — Collected in flower and fruit by Parry & Palmer (n. 876) in the mountains near San Luis Potosi.

5. D. ACROTRICHUM, Zucc. Described as resembling the last, with panicle narrower and the floral bractlets entire. Fruit not known.— Baker, l. c.

6. D. SERRATIFOLIUM, Zucc. A similar species, imperfectly known; leaves not breaking up into fibres at the end. — Baker, l. c. 298.

7. D. LAXIFLORUM, Baker, l. c. 299. Leaves also not fibre-tipped: panicle ovate-thyrsoid. Female flowers and fruit unknown.

8. D. QUADRANGULATUM. Caudex 3 feet high: leaves drooping, dark green, 2 feet long or more, 2 or 3 lines broad at base, soon narrower and quadrangular (nearly square in section), unarmed, scabrous: scape about 5 feet high; inflorescence narrow: flowers 1½ lines long, on very short pedicels: fruit 3½ to 5 lines long, the broad wings produced upward to the summit of the slender style: stigma-lobes spreading: seed 2 lines long.— Sierra Nola, Tamaulipas; Dr. E. Palmer, 1878: a very peculiar species.

23. HESPEROCALLIS, Gray.

1. H. UNDULATA, Gray. Bulb large: stem stout, leafy, a foot or two high, 5–8-flowered: leaves linear, fleshy, carinate, 3 to 6 lines wide, the margin undulate: flowers 1½ to 2 inches long, on short pedicels; segments 5–7-nerved: style exserted, the capsule acute with its persistent base, sessile, a half-inch long: seeds thin, 2½ to 3 lines broad.— Proc. Am. Acad. 7. 390; Baker, Trim. Journ. Bot. 11. 359. Colorado Desert.

24. HESPERALOE, Engelm.

1. H. YUCCÆFOLIA, Engelm. Stem 2 to 4 feet high, sparingly branched: leaves a foot or two long, 3 or 4 lines broad, recurved, long-attenuate: bracts broad and acuminate, rather large: pedicels cymose-fascicled, 4 to 18 lines long: flowers a half to an inch long, with erect segments: stamens somewhat shorter; anthers small (a line long): style equalling the perianth, at length exserted, 2 or 3 or more times longer than the ovary: capsule ovate, acute, an inch long.— King's Rep. 5. 497. *Yucca (?) parviflora*, Torr. Bot. Mex. Bound. 221. *Aloe yuccæfolia*, Gray, Proc. Amer. Acad. 7. 390. W. Texas (from Frio County to mouth of the Pecos). A second species from the same region has been proposed (*H. Engelmanni*, Krauskopf), but is imperfectly known, perhaps to be distinguished by its more slender and flexuous branches and smaller bracts, its twice longer anthers, and the stouter included style scarcely longer than the ovary.

25. YUCCA, Linn.

* **Filaments obtuse, papillose; anthers cordate-sagittate: ovary narrowly oblong: stigmas more or less distinct, papillose. — § Euyucca, Engelm.**

+ **Fruit baccate, pendulous: seeds thick, rugose, not margined, with lobed or ruminated albumen. Mostly arborescent, with sessile panicle.**

++ **Leaves serrulate.**

1. Y. ALOIFOLIA, Linn. Caudex 6 to 12 feet high, simple or sparingly branched: leaves thick, very rigid, tipped with a stout brown spine, 1 to 2 feet long or more, by an inch or two wide: panicle with rather small triangular bracts, smooth: flowers 1½ inches long; segments ovate: stigmas sessile, short and thick, straight: fruit 6-sided, 3 or 4 inches long, acutish: seeds 3 lines broad, half as thick. — Ker, Bot. Mag. t. 1700; Engelm. Trans. St. Louis Acad. 3. 34. *Y. Draconis*, Linn.; Lindl. Bot. Reg. t. 1894; with longer and softer leaves. *Y. conspicua*, Haw., branching from the base, with softer green-pointed leaves. Coast region, from North Carolina to Alabama. The varieties are only known in foreign gardens, under various names.

Dr. Engelmann describes two other species, — Y. YUCATANA, from Yucatan, 20 feet high, branching from the base: leaves slightly rough on the margin, a foot long or more: panicle densely villous, with lanceolate bracts: perianth-segments ovate-lanceolate: stamens much shorter than the ovary, — and Y. GUATEMALENSIS, Baker (Saund. Ref. Bot. t. 313), from Mexico and Guatemala, with scarcely pungent and slightly serrulate leaves 2½ or 3 feet long. flowers 3 inches long with lanceolate segments, and a short thick ovary with deeply 2-lobed spreading stigmas.

++ ++ **Margin of the leaf entire (often serrulate when young or sparingly filamentose when old).**

2. Y. GLORIOSA, Linn. Caudex 4 to 6 feet high or less, simple or sparingly branched: leaves straight and rigid, pungent, often folded, 2 to 2½ feet long, roughish on the back: panicle pedunculate, smooth or pubescent, 2 to 4 feet long, with broad lanceolate bracts: flowers cream-white, often greenish or reddish; segments ovate, acute, 1½ inches long or more: stamens as long as the ovary: stigmas rather slender, at length divergent. — Ker, Bot. Mag. t. 1260; Engelm. l. c. 38. *Y. acuminata*, Sweet, Fl. Gard. t. 195. *Y. recurvifolia*, Salisb. Parad. t. 31. Sea-coast, North Carolina to Florida; in cultivation under numerous names and in several forms (Baker, Saund. Ref. Bot. t. 316–321; Carr. Rev. Hort. t. 89, 104).

3. Y. CANALICULATA, Hook. Caudex 6 to 25 feet high, branching at top: leaves very long (2½ to 4½ feet by 2 or 3 inches wide), straight and very rigid, deeply channelled, rough on the back: panicle subsessile, ovate, 2 to 4 feet long, densely flowered, nearly glabrous, with large ovate or broadly lanceolate bracts: flowers cream-white; segments ovate or ovate-lanceolate, acute or acuminate, 1½ to 2½ inches long: filaments scarcely papillose, nearly equalling the pistil: style slender; stigmas narrow, deeply 2-lobed: fruit subcylindric, strongly beaked, 3 or 4 inches long: seeds 3 to 3½ lines broad. — Bot. Mag. t. 5201. *Y. Treculiana*, Carr. Rev. Hort. 7. 280 (name only); Engelm. l. c. 41. *Y. longifolia*, Engelm.; Buckley, Proc. Philad. Acad. 1862, 8. Texas to Northern Mexico.

++ ++ ++ Leaves coarsely filamentose on the margin.

4. Y. BACCATA, Torr. Caudex short or none: leaves very thick and rigid, 1½ to 3 feet long by an inch or two wide, channelled or concave, rough especially on the back, tipped by a very stout brown spine: panicle pedunculate, usually glabrous, with ovate-lanceolate or ovate bracts: perianth-segments narrow, 2½ to 3 inches long: stamens equalling the ovary: style more or less elongated, slender: fruit oval or cylindric, 3 to 5 inches long, dark purple, often long-beaked: seeds 4 to 8 lines broad, a line thick or more. — Bot. Mex. Bound. 221: Engelm. l. c. 44: Ill. Hort. 3 ser. t. 115. S. Colorado and W. Texas to S. California and Northern Mexico.

Var. AUSTRALIS, Engelm. l. c. Caudex taller (often 10 to 50 feet), branching: leaves thinner and smoother, with finer fibres: flowers smaller (1½ inches long), with ovate segments and short style. — The more southern Mexican form.

5. Y. SCHOTTII, Engelm. l. c. 46. Caudex 2 to 5 feet high, branched from the base: leaves straight, rigid, about 9 inches long by 6 or 8 lines wide, concave, somewhat pungent, smooth, with very slender straight marginal threads: panicle loosely flowered, with flexuous peduncle and branches, and large lanceolate bracts: flowers rather small: style and stigmas short: fruit ovate, 2 inches long, shortly beaked. — S. Arizona.

+- +- Fruit becoming dry and spongy, indehiscent, erect: seeds thickish, smooth and scarcely margined, with entire albumen. Tall and branching, with sessile panicles and serrulate leaves.

6. Y. BREVIFOLIA, Engelm. Caudex 15 to 30 feet high: leaves 3 to 8 inches long by as many lines wide, very rough and rigid, attenuate to a stout spine, nearly flat above: panicle pyramidal, with white

ovate to lanceolate bracts: flowers crowded, erect on very short pedicels, fetid, greenish white; segments narrowly lanceolate, 1½ to 2 inches long: stamens half the length of the ovary: stigmas short, sessile: fruit ovate, 2 or 3 inches long. — King's Rep. 5. 496, and l. c. 47. *Y. Draconis*, var. (?) *arborescens*, Torr. Pacif. R. Rep. 4. 147. Southeastern California to S. Utah.

+ + + Fruit capsular, septicidal and at length loculicidal at top, erect: seeds thin, smooth, broadly margined, with entire albumen. Caudex none or short, the panicle upon a tall scape.

++ Leaves serrulate.

7. Y. RUPICOLA, Scheele. Acaulescent: leaves a foot or two long by an inch or two wide, rigid, erect and pungent, smooth, deep green, mostly oblique and undulate or twisted, with coarse reddish serratures: scape 4 to 7 feet high, with long and narrow bract-like leaves: panicle pyramidal, few-flowered; bracts small: flowers greenish white; segments ovate, sharply acuminate, 1½ to 3 inches long: stamens straight, equalling the ovary: style slender: capsule 6-sided, acute or beaked, 2 or 2½ inches long: seeds 3½ to 4 lines broad. — Linnæa, 23. 143; Engelm. l. c. 48. *Y. lutescens*, Carr. Western Texas.

Var. RIGIDA, Engelm. l. c. Leaves pale and glaucous, not twisted, carinate and often rough on the back, 8 to 12 inches long by 3 to 6 lines wide: capsule and seeds smaller. — Eastern New Mexico and Northern Mexico.

++ ++ Margin of the leaves filamentose.

8. Y. ANGUSTIFOLIA, Pursh. Leaves straight, very stiff and pointed, usually 1 to 3 feet long by 3 to 6 lines wide, smooth: raceme usually simple, nearly sessile, 1 to 4 feet long: flowers greenish white or tinged with brown; segments broadly ovate, an inch or two long: stigmas green, shorter than the ovary: capsule 6-sided, 3 inches long, half as wide: seeds broadly margined, 5 or 6 lines broad. — Sims, Bot. Mag. t. 2236; Engelm. l. c. 50. Dakota to New Mexico.

Var. ELATA, Engelm. l. c. Caudex 3 to 5 feet high, with numerous glaucescent sometimes entire leaves ½ to 1½ feet long: panicle oblong or lanceolate, 3 or 4 feet long, as long as the peduncle: flowers white, with narrower segments. — *Y. constricta*, Buckl. Proc. Philad. Acad. 1862, 8? W. Texas to Utah and Northern Mexico. Various cultivated forms are probably referable to this (Baker, Gard. Chron. 1870, 1088).

Var. MOLLIS, Engelm. l. c. Acaulescent: leaves softer and less pungent, broadest (5 to 8 lines) in the middle: raceme or panicle ½ to

1 foot long, on a peduncle 2 or 3 feet high: flowers greenish: capsule shorter (2 inches long): seeds more narrowly margined. — *Y. stricta*, Sims, Bot. Mag. t. 2222. Arkansas to Louisiana and Texas.

9. Y. FILAMENTOSA, Linn. Caudex a foot high or less: leaves numerous, rather rigid, straight, with short point, rough on the back, 1½ to 2 feet long by 12 to 18 lines wide (sometimes oblanceolate or spatulate and obtuse, 2 or 3 inches wide, concave): panicle pyramidal, densely flowered, glabrous, on a stout scape 4 to 9 feet high; bracts of the scape short, oblique, spatulate: flowers greenish white, 1 to 1½ inches long: stamens equalling the pistil: stigmas pale, elongated, at length recurved: capsule cuspidate, 1½ inches long: seeds 3 lines broad. — Sims, Bot. Mag. t. 900; Baker, Saund. Ref. Bot. t. 324, 325; Engelm. l. c. 51. *Y. concava*, Haw. *Y. glaucescens*, Haw.; Sweet, Fl. Gard. t. 53. Near the coast, from Maryland to Florida and Louisiana.

Var. FLACCIDA, Engelm. l. c. Mostly stemless: leaves soft and flaccid, thin and flat, with a weak point and usually numerous very slender threads: panicle contracted, pubescent, as long as the scape: stigmas shorter, attenuate, connivent; capsule angled, 2½ inches long: seeds 4 or 5 lines broad. — *Y. flaccida*, Haw.; Lindl. Bot. Reg. t. 1895; Baker, l. c., t. 323. *Y. puberula*, Haw.; Sweet, Fl. Gard. t. 21; Baker, l. c., t. 322. *Y. glauca*, Sims, Bot. Mag. t. 2662; Baker, l. c., t. 315. *Y. exigua*, Baker, l. c., t. 314.

Var. (?) BRACTEATA, Engelm. l. c. Leaves rather rigid, roughish, with a slender sharp point: bracts of the scape larger and foliaceous, tapering upward: panicle contracted, half as long as the scape, rough or pubescent: stamens half as long as the pistil. — Coast of S. Carolina.

Var. (?) LÆVIGATA, Engelm. l. c. Leaves fewer, smooth, rigid and pungent, very long (2½ to 3½ feet long by 10 to 15 lines wide), soon decumbent: scape 8 or 10 feet high, with lanceolate bracts, much longer than the pyramidal smoothish panicle: stigmas distinct to the base, deeply 2-lobed, erect. — S. Carolina to Florida.

* * Filaments acute, glabrous, erect: anthers broadly cordate, didymous: ovary obovate; stigma capitate-peltate, hairy-papillose: capsule loculicidal: seeds thin, smooth, with entire albumen. — § HESPEROYUCCA, Engelm.

10. Y. WHIPPLEI, Torr. Caudex none or very short: leaves rigid, serrulate, smooth, carinate, nearly flat but concave toward the apex and attenuate to a stout brown spine, 10 to 20 inches long by 4 to 7 lines broad: scape 4 to 12 feet high, with imbricated sheathing bracts: panicle narrow and spike-like, dense, smooth: flowers greenish white,

subrotate; segments oblong-lanceolate, 1 or 2 inches long: style short, conical; stigma green, slightly 3-lobed: capsule globose-ovate, an inch or two long: seeds 3 or 4 lines broad. — Bot. Mex. Bound. 222; Engelm. l. c. 54. *Y. aloifolia*, Torrey, Pacif. R. Rep. 4. 147. San Francisco to San Diego and Arizona. *Y. graminifolia*, Wood (Proc. Acad. Philad. 1868, 167), appears to be a variety with longer and narrower leaves (20 inches long by 3 lines wide), laxer and more channelled, revolute toward the apex and tipped by a more slender spine.

26. LILIUM, Tourn.

* Perianth-segments unguiculate.

+ Flowers erect, usually solitary; segments abruptly narrowed to the claw, coarsely spotted on the lower half: leaves linear-lanceolate: bulbs not rhizomatous. Atlantic States.

1. L. Philadelphicum, Linn. Bulb small, of thick fleshy jointed scales: leaves whorled or scattered: perianth-segments reddish-orange, acute, spreading, 2 to 4 inches long. — Curtis, Bot. Mag. t. 519; Ker, Bot. Reg. t. 594; Baker, Journ. Linn. Soc. 14. 235; Babbage, Garden, 11. 135, fig. (bulb); Elwes, Monogr. Lil. t. 10. *L. andinum*, Nutt. Fras. Cat. *L. umbellatum*, Pursh. Canada to the Saskatchewan and south to N. Carolina and Colorado.

2. L. Catesbæi, Walt. Bulb-scales thin, narrow and leaf-bearing: leaves scattered: perianth-segments scarlet with yellow base, long-acuminate, undulate, recurved above, 3 to 5 inches long, the claw very narrow. — Curtis, Bot. Mag. t. 259; Sweet, Fl. Gard. 2 ser. t. 185; Baker, l. c. 240; Babbage, l. c., fig. (bulb); Elwes, l. c., t. 28. *L. spectabile*, Salisb. Stirp. Rar. t. 5. N. Carolina to Florida, in pine-barrens.

+ + Flowers horizontal or ascending, usually several; segments narrowing gradually into the claw, spotless or finely dotted: leaves oblanceolate or linear-lanceolate: bulbs somewhat rhizomatous. Pacific Coast.

3. L. Washingtonianum, Kellogg. Bulbs large; scales not jointed: leaves oblanceolate, more or less verticillate: flowers horizontal, white becoming purplish, very fragrant; segments 3 or 4 inches long, not recurved: anthers 5 or 6 lines long: capsule obovate, truncate. — Proc. Calif. Acad. 2. 13; Wood, Proc. Philad. Acad. 1868, 166; Baker, Gard. Chron. 1871, 709, f. 142, and l. c. 232; Regel, Gartenfl. t. 710; Fl. Serres, t. 1795; Babbage, l. c., fig. (bulb). Oregon and southward in the Sierra Nevada; Cuyumaca Mountains.

4. L. RUBESCENS. Similar, but bulbs small (2 inches in diameter): flowers erect or ascending, with revolute segments, usually 1½ or 2 inches long, sometimes more, pale lilac or nearly white, becoming rose-purple: anthers 2 or 3 lines long. — *L. Washingtonianum*, var. *purpureum*, Masters, Gard. Chron. 2. 2. 322, f. 67; Baker, l. c. 233. California (Coast Range, Marin to Humboldt Counties).

5. L. PARRYI, Watson. Bulb small, with jointed scales: leaves linear-oblanceolate, usually scattered: flowers horizontal, pale yellow; segments about 3 inches long, with spreading or recurved tips: capsule narrowly oblong. — Proc. Davenport Acad. 2. 188, t. 5, 6. California (San Gorgonio Pass, San Bernardino County).

* * Segments oblanceolate, yellow or orange, coarsely spotted with brown. Flowers erect or horizontal, small.

+ Species of Atlantic States. [See page 301.]

6. L. GRAYI. Leaves lanceolate, 2 inches long or less, in whorls of 4 to 8, not acuminate: flowers 1½ to 2½ inches long, horizontal, often solitary; segments spreading but not recurved, apparently deep reddish-orange, covered throughout with purplish spots. — Summit of Roan Mountain (Gray, 1840) and Peaks of Otter (A. H. Curtiss, July, 1871). The specimens are scanty, but appear very distinct.

+ + Californian species.

7. L. PARVUM, Kellogg. Bulb rhizomatous, of small narrow jointed scales: leaves mostly verticillate, acute or acuminate: flowers few to very many, suberect, 1 to 1½ inches long, yellow or orange, rather finely dotted except on the reddish spreading or recurved tips: anthers a line or two long: capsule subglobose, truncate, 6 to 9 lines long. — Proc. Calif. Acad. 2. 179, f. 12; Regel, Gartenfl. 1872, t. 725; Elwes, Monogr. t. 24. *L. Canadense*, var. *Walkeri*, Wood, l. c. 166, and var. *parvum*, Baker; Hook. f. Bot. Mag. t. 6146; Babbage, l. c. 156, fig. (bulb). In the Sierra Nevada to Oregon.

8. L. MARITIMUM, Kellogg. Bulb small, conical: stem rather low: leaves usually scattered, narrow, often obtuse: flowers solitary or few, horizontal, 1½ to 2 inches long, deep reddish-orange, spotted below; segments recurved above: style and stamens short; anthers 2 lines long: capsule "long and narrow." — Proc. Calif. Acad. 6, 140. *L. Canadense*, var. *parviflorum*, Bolander, same, 5. 206. Swamps, Marin to Humboldt Counties.

+ + Flowers nodding, large.

+ Species of the Atlantic States.

9. L. CANADENSE, Linn. Tall, rhizomatous: leaves usually verticillate, lanceolate to linear-lanceolate, acuminate, scabrous on the

veins beneath: flowers yellow, spotted below, the segments spreading and somewhat recurved above: capsule oblong-obovate. — Ker, Bot. Mag. t. 800, 858; Fl. Serres, t. 1174; Baker, Journ. Linn. Soc. 14. 240, excl. vars.; Babbage, l. c. 156, fig. (bulb). *L. penduliflorum*, DC.; Red. Lil. t. 105. *L. pardalinum*, var. *Bourgæi*, Baker, l. c. 242. Canada (N. Brunswick to Rainy River) to Georgia.

10. L. SUPERBUM, Linn. Like the last, but the perianth-segments spreading from the base and strongly revolute: leaves often scattered, smooth: capsule somewhat broader. — Ker, Bot. Mag. t. 936; Fl. Serres, t. 1014; Baker, l. c. 242, excl. vars.; Elwes, l. c., t. 21. Canada (N. Brunswick to W. Ontario) and southward.

Var. CAROLINIANUM, Chapm. Low: flowers few (1 to 3). — Baker, l. c. *L. Carolinianum*, Michx.; Ker, Bot. Reg. t. 580; Sims, Bot. Mag. t. 2280; Elwes, l. c., t. 28. *L. Michauxii*, Poir. Suppl. 3. 457. *L. autumnale*, Lodd. Bot. Cab. t. 335.

++ ++ Pacific Coast: flowers few to many, with revolute segments.

11. L. COLUMBIANUM, Hanson. Bulb small, not rhizomatous, the scales not jointed: leaves usually in whorls of 5 to 9 or more, 2 to 4 inches long, flat and smooth: flowers bright reddish-orange, with strongly revolute segments, 1½ to 2 inches long: stamens short; anthers 2 or 3 lines long: capsule oblong, an inch long, acutely 6-angled. — Baker, l. c. 243; Babbage, l. c., fig. (bulb); Elwes, Monog. t. 32. *L. Canadense*, var. *parviflorum*, Hook. Fl. Bor.-Am. 2. 181, and var. *minus*, Wood, l. c. 166. *L. lucidum*, Kellogg, Proc. Calif. Acad. 6. 144. *L. Humboldtii*, var., Babbage, l. c. From British Columbia to Northern California in the Sierra Nevada.

12. L. HUMBOLDTII, Roezl & Leicht. Bulb as in the last, but large: leaves in whorls of 10 to 20, undulate, somewhat scabrous: flowers reddish-orange, 3 or 4 inches long; segments strongly revolute, the outer abruptly narrowed to a short broad claw: anthers 4 to 8 lines long: capsule large, obovoid, acutely 6-angled. — Regel, Gartenfl. 1872, t. 724; Fl. Serres, t. 1973; Baker, l. c. 244; Elwes, l. c., t. 31. *L. Canadense*, var. *puberulum*, Torr. Pacif. R. Rep. 4. 146, and var. *Humboldtii*, Baker, Gard. Chron. 1871, 1165. *L. Bloomerianum*, Kellogg, Proc. Calif. Acad. 4. 160, and 5. 88, f. 4 (var. *ocellatum*). In the dry higher foothills of the Sierra Nevada (Butte County and southward) and Coast Ranges from Santa Barbara to San Diego.

13. L. PARDALINUM, Kellogg. Rhizome thick and branching; scales jointed below: leaves flat, smooth, narrowly lanceolate to linear, the middle in whorls of 9 to 15: flowers bright orange-red,

lighter yellow in the centre, 2 or 3 inches long; segments strongly revolute: anthers 4 or 5 lines long: capsule narrowly oblong, 1½ inches long or more. — Proc. Calif. Acad. 2. 12; Baker, l. c. 242; Elwes, l. c., t. 26. *L. Californicum*, Lindl.; Florist, 1873, t. 33. *L. superbum*, var. *pardalinum*, Baker, Journ. Hort. Soc. 1873, 45. *L. Canadense*, var. *pardalinum* and var. *Californicum*, Bolander, Proc. Calif. Acad. 5. 206. Coast Ranges and foothills of the Sierra Nevada (in wet places) from Central California northward.

Var. ANGUSTIFOLIA, Kellogg. The form with narrow scattered leaves. — *L. Roezli*, Regel, Gartenfl. 1870, t. 667; Baker, Journ. Linn. Soc. 14. 243. *L. Canadense*, var. *Hartwegi*, Baker, Gard. Chron. 1871, 1165.

27. FRITILLARIA, Linn.

* Styles distinct to the middle; stigmas linear.

+ Capsule rather obtusely angled: flowers mostly large (an inch long): bulb-scales 3 or 4 lines long. — § LILIORHIZA, Baker.

1. F. RECURVA, Benth. Bulb-scales numerous and thick: leaves linear-lanceolate, mostly in two whorls near the middle of the stem: flowers 1 to 7, tinged or blotched with light purple or scarlet, 12 to 18 lines long; segments narrowly oblanceolate with recurved tips: stamens a little shorter, equalling the very slender style. — Pl. Hartw. 340; Baker, Journ. Linn. Soc. 14. 272, and Bot. Mag. t. 6264 (poor). Sierra Nevada (Placer County to Oregon).

2. F. LILIACEA, Lindl. Bulb-scales few, very thick: leaves oblanceolate to linear, approximate or whorled near the base: flowers 1 to 5, greenish white (not blotched), 8 to 12 lines long; segments oblanceolate, spreading: anthers shorter (1 to 1½ lines): style stout. — Baker, l. c. 273. *F. alba*, Kellogg, Proc. Calif. Acad. 1. 46. *Liliorhiza lanceolata*, Kellogg, l. c. 2. 46, f. 1; Regel, Gartenfl. 1872, t. 715. Lower Sacramento Valley; stamens much shorter than the styles, as in all the following species.

3. F. BIFLORA, Lindl. Usually low: bulb-scales few, ovoid, often tipped with a small scarious blade: leaves narrowly lanceolate to oblong-lanceolate, few, scattered or somewhat whorled near the base: flowers 1 to 3, dark brownish or greenish purple; segments oblanceolate, widely spreading: style stout: capsule broadly obovoid. — Baker, l. c. *F. Kamschatcensis*, auth. *F. lanceolata*, Torr. Bot. Mex. Bound. t. 61. *F. Grayana*, Reich. f. & Baker, Trim. Journ. Bot. 1878, 262. Coast Ranges, from Mendocino County to San Diego.

4. F. KAMSCHATCENSIS, Ker. Resembling the last, but usually taller, with more numerous leaves on the upper portion of the stem: capsule broadly oblong-ovate. — Hook. Fl. Bor.-Am. 2. 181, t. 193, A; Baker, l. c. 273. *Lilium*, Linn. *L. quadrifoliatum*, E. Meyer, Rel. Hænk. 2. 126. *L. affine*, Schult. Syst. 7. 40, in part. Alaska and E. Siberia.

+ + Capsule acutely angled or winged: bulb-scales thick, about half an inch long. — § GONIOCARPA, Baker.

++ Flowers usually large: leaves lanceolate to linear-lanceolate.

5. F. LANCEOLATA, Pursh. Leaves in 1 to 3 whorls above the middle of the stem: flowers 1 or 2, brownish purple mottled with greenish yellow; segments narrowly oblanceolate: stamens 6 or 8 lines long. — Hook. l. c., t. 193, B; Baker, l. c. 271. British Columbia to Mendocino County; the following varieties in Central California (Coast Ranges and foothills of the Sierra Nevada).

Var. FLORIBUNDA, Benth. Flowers 4 to 8 or rarely fewer, lighter colored (greenish yellow blotched with purple); segments 4 to 6 lines broad, strongly arched with broad nectaries, acute: lower pedicels an inch long or more. — Pl. Hartw. 338. *F. mutica*, Lindl. *F. viridia*, Kellogg, Proc. Calif. Acad. 2. 9. *Liliorhiza viridia*, Kellogg, l. c. 2. 48.

Var. GRACILIS. Flowers smaller than the last, with narrow and more acuminate segments: stamens short and anthers often small. — *F. lanceolata*, var. (?), Benth, l. c. 340 (n. 2005, Hartw.; n. 350, Bridges; n. 3969, Bolander).

++ ++ Flowers smaller: leaves linear.

6. F. PARVIFLORA, Torr. Leaves mostly whorled: flowers 3 to 20, on short strongly recurved pedicels, yellowish tinged with purple; segments less arched, with shallow nectaries. — Pacif. R. Rep. 4. 146; Baker, l. c. 272. *F. multiflora*, Kellogg, l. c. 1. 57? Sierra Nevada (Calaveras County).

7. F. ATROPURPUREA, Nutt. Usually low and more slender: leaves scattered or somewhat whorled: flowers 1 to 6, dull purple with more or less of yellowish green, on slender pedicels. — Journ. Acad. Philad. 7. 54; Baker, l. c. Sierra Nevada (Placer County to the Columbia) and east to Utah and Wyoming.

* * Styles connate to the summit; stigma 3-lobed: capsule obtusely angled: flowers not mottled, with obscure nectaries: leaves narrow or linear, scattered or somewhat whorled. — § AMBLIRION, Baker.

8. F. PLURIFLORA, Torr. Bulb-scales a half to one inch long: stem usually tall, 4–12-flowered: leaves 8 to 15: flowers reddish

purple, 9 to 12 lines long, on long pedicels. — Benth. Pl. Hartw. 338; Baker, l. c. 270. Sierra Nevada (Butte and Placer Counties).

9. F. PUDICA, Spreng. Bulb-scales very small and rounded: stem low, usually 1–3-flowered: leaves 3 to 8: flowers yellow or orange, tinged outside with purple, 5 to 9 lines long. — Baker, l. c. 267. *Lilium* (?) *pudicum*, Pursh, Fl. 228, t. 8. *Amblirion pudicum*, Raf.; Torr. Stansb. Rep. 396, t. 9. *Theresia pudica*, Klatt, Hamb. Gart. 16. 439. Northern Sierra Nevada to British Columbia, and east to Utah and Montana.

28. ERYTHRONIUM, Linn.

* Flowers solitary: capsule obovate: often propagating by offshoots or runners.

1. E. AMERICANUM, Smith. Offshoots arising from the base of the bulb: leaves oblong-lanceolate, mottled and dotted: flower light yellow, often dotted at base, 10 to 20 lines long: style club-shaped and stigmas coherent: capsule 6 lines long. — Ker, Bot. Mag. t. 1113; Bigel. Med. Bot. 3. 151, t. 58; Baker, Journ. Linn. Soc. 14. 298. *E. dens-canis*, var., Linn. *E. Carolinianum*, Walt. *E. lanceolatum*, Pursh. *E. angustatum* and *flavum*, Raf. *E. bracteatum*, Boott. *E. Nuttallianum*, Schult.; Regel, Gartenfl. 1871, t. 695. Canada (New Brunswick to W. Ontario) to Florida and Arkansas.

2. E. ALBIDUM, Nutt. Like the last, but leaves usually narrower and not mottled nor dotted: flowers bluish-white; segments not toothed at base: style more slender, the stigmas somewhat spreading. — Gen. 1. 223; Baker, l. c. 298. New York and Pennsylvania to Minnesota and Texas.

3. E. PROPULLANS, Gray. Offshoot arising from the stem near the middle: leaves smaller and more acuminate: flowers bright rose-color, yellowish at base, 6 lines long: style slender; stigmas coherent. — Amer. Naturalist, 5. 298, f. 74; Baker, l. c. 299. Minnesota.

* * Flowers one to several: capsule oblong: new corms sessile at the base of the old.

4. E. GRANDIFLORUM, Pursh. Corm often 2 inches long, narrow: leaves not mottled, opposite: flowers solitary or racemose (1 to 6), yellow or cream-colored with a more or less orange base, 1 or 2 inches long: filaments slender: stigmas at length spreading: ovary and capsule (an inch long or more) narrowly oblong. — Lindl. Bot. Reg. t. 1786; Regel, Gartenfl. 1876, t. 874, f. 6; Baker, l. c. 297. Oregon and Washington Territory. The following varieties need farther investigation.

Var. (?) ALBIFLORUM, Hook. Flowers large, white with yellow and orange base: leaves mottled. — Fl. Bor.-Am. 2. 182; Regel, Gartenfl. 1874, t. 767, f. 1–4. *E. giganteum*, Lindl. l. c.?; Hook. Bot. Mag. t. 5714. *E. grandiflorum*, Van Houtte, Fl. Serres, t. 2117. Washington Territory.

Var. (?) MINOR, Morren. Flowers small (an inch long), bright yellow. — Belg. Hort. 26. 109, t. 6. Utah and Colorado.

Var. (?) SMITHII, Hook. Flowers large, tinged with purple or rose-color: filaments often dilated: ovary broader and more obtuse. — Fl. Bor.-Am. 2. 182. *E. revolutum*, Smith, Rees' Cyc. Vancouver Island; Mendocino County, California (n. 4709, Bolander).

5. E. HARTWEGI. Bulb small: leaves usually more or less separated, apparently mottled, often rather small: flowers solitary, or 2 or 3 in a sessile umbel, light yellow and orange, 1 or 2 inches long, the segments spreading or scarcely recurved: filaments usually short, slender; anthers 2 to 4 lines long: ovary ovate-oblong. — *E. grandiflorum*, Benth. Pl. Hartw. 339. Sierra Nevada (Placer to Plumas Counties).

6. E. PURPURASCENS, Watson. Bulb an inch or two long: leaves undulate, often large: flowers usually 4 to 8 in a pedunculate sub-umbellate raceme, light yellow tinged with purple, deep orange at base, 9 to 12 lines long: pedicels very unequal: anthers a line or two long: style clavate: capsule narrow, about an inch long. — Proc. Amer. Acad. 12. 277. *E. grandiflorum*, var. *multiflorum*, Torr. Pacif. R. Rep. 4. 146, and var. *multiscapidea*, Wood, Proc. Philad. Acad. 1868, 166. *Fritillaria multiscapidea*, Kellogg, Proc. Calif. Acad. 1. 46. *E. revolutum*, Baker, Gard. Chron. 1876, 138, seems to be only a very slender 1-flowered form of this species. Sierra Nevada (Placer to Plumas Counties).

29. LLOYDIA, Salisb.

1. L. SEROTINA, Reichenb. Stem 2 to 6 inches high, equalling the leaves: flowers erect, usually solitary; perianth-segments oblanceolate, obtuse, obscurely pitted at base, 4 or 5 lines long, exceeding the stamens and style: capsule obovate, obtusely angled, 4 lines long: seeds chestnut-colored. — *Ornithogalum bracteatum*, Torrey, Ann. Lyc. N. Y. 2. 251. *Cronyxium serotinum* and *Fenelonia bracteata*, Raf. Alpine and arctic regions of the northern hemisphere; Alaska and Arctic Coast, Rocky Mountains of Colorado to 38° lat., and on the Clover Mountains, Nevada.

30. CALOCHORTUS, Pursh.

* Inner perianth-segments (*petals*) strongly arched and broadly pitted, the gland usually with a transverse scale or fringe; outer segments (*sepals*) naked, rarely spotted: capsule more or less broadly elliptical, obtuse or acute, deeply triquetrous with thin acute or winged lobes, septicidal: seeds mostly brownish with close pitted testa: flowers or fruit more or less nodding, and stem usually lax. — § EUCALYCHORTUS.

+ Flowers subglobose, nodding: stem usually tall and branching.

1. C. ALBUS, Dougl. Stem 1 to 3 feet high: flowers white with purplish base: petals acutish, an inch long, bearded and ciliate: gland lunate, with four transverse imbricate fringed scales: capsule short-beaked, an inch or two long, half as wide. — Maund, Bot. t. 98; Baker, Journ. Linn. Soc. 14. 304. *Cyclobothra alba*, Benth. Trans. Hort. Soc. 1. 413, t. 14, f. 3; Lindl. Bot. Reg. t. 1661; Fl. Serres, t. 1171. *C. paniculata*, Lindl. California (Los Angeles to Sonoma County and foothills of the Sierra Nevada).

2. C. PULCHELLUS, Dougl. Stem usually a foot high or more: flowers yellow or orange: petals ciliate and bearded with glandular-tipped hairs, deeply pitted, the gland covered by the reflexed stiff hairs of its upper margin: anthers obtuse: capsule obtuse, an inch long or more. — Baker, l. c. 303. *Cyclobothra pulchella*, Benth. l. c., t. 14, f. 1; Lindl. l. c., t. 1662; Regel, Gartenfl. t. 802. California (Monterey to Mendocino County).

+ + Flowers campanulate, erect when open; pedicels becoming recurved: stem mostly low and flowers often subumbellate.

++ Flowers yellow.

3. C. BENTHAMI, Baker, l. c. 304. Resembling the last: stem low and leaves narrow: flowers nearly erect: petals a half-inch long, mostly obtuse, often deep brown at base, with shallower pit: anthers acute: capsule 6 to 9 lines long. — *Cyclobothra elegans*, var. *lutea*, Benth. Pl. Hartw. 338. California (in the Sierra Nevada, Mariposa to Butte Counties).

++ ++ Flowers white or light lilac.

= Petals covered with hairs and mostly ciliate.

4. C. MAWEANUS, Leichtlin. Low, usually branched; bracts an inch long or more: petals white, purplish at the broad base, 6 to 8 lines long, somewhat pitted, the gland covered by a broad transverse semicircular scale: anthers lanceolate, acuminate: capsule oblong-elliptic, acutish. — *C. elegans* of California, mainly; Hook. f. Bot. Mag. t. 5976; Baker, l. c. 305. California (Coast Ranges, from San Francisco to Humboldt County, and near Chico).

5. C. CÆRULEUS. Low, umbellately 2–5-flowered; pedicels very slender: bracts smaller: petals 6 or 7 lines long, lilac dotted and lined with blue, with narrower claw, and the gland covered by an appressed fringed scale: anthers oblong, obtuse: capsule orbicular or nearly so, obtuse, 6 lines long. — *Cyclobothra elegans*, var., Benth. Pl. Hartw. 338. *C. cærulea*, Kellogg, Proc. Calif. Acad. 2. 4. *C. glaucus*, Regel, Act. Hort. Petrop. 3. 285? California (in the Sierra Nevada, Placer to Plumas Counties; Hartweg, n. 1988; etc.).

6. C. ELEGANS, Pursh. Similar in habit: petals greenish white, purplish at base, bearded but not ciliate or only sparingly so, the lunate gland covered by a very narrow and deeply fringed scale: anthers long-acuminate: capsule as in the last. — Dougl. Hort. Trans. 7. 278, t. 9, f. B. *Cyclobothra*, Lindl. Oregon and Idaho.

Var. NANUS, Wood. Subalpine, dwarf and very slender: petals narrow and often acute or acuminate, more hairy and ciliate. — Proc. Philad. Acad. 1868, 168. *C. Lyallii*, Baker, l. c. 305. Siskiyou Mountains, California; Mount Hood, Oregon, and northward to British Columbia.

7. C. TOLMIEI, Hook. & Arn. Stouter and taller (a foot high), usually branched: petals 9 to 15 lines long, tinged or marked with lilac, covered and fringed with purple and white hairs; gland without scale, bordered above by a dense fringe of reflexed hairs: anthers lanceolate, acuminate, 2 or 3 lines long: capsule broadly elliptic, acutish at each end, 10 to 15 lines long. — Bot. Beechey, 398. *C. elegans*, var., Baker, l. c. 305. Oregon to base of Mount Shasta.

8. C. APICULATUS, Baker, l. c. 305. A similar species, but still taller and stouter, with an umbel of larger straw-colored flowers. — Northern Idaho.

= = Petals hairy only toward the base or wholly naked.

9. C. NUDUS. Low: leaf solitary, 3 to 10 lines broad: bracts small (rarely an inch long): flowers 1 to 6, in a single umbel: petals 4 to 10 lines long, white or pale lilac, without hairs, denticulate; gland with a broad transverse appressed scale: anthers linear-oblong (2 or 3 lines long), obtuse: capsule oblong, acute at each end, 8 or 10 lines long: seeds yellowish, papillose, with a white vesicle at base. — *C. elegans*, var. *subcalvatus*, Baker, l. c. 305. California (in the Sierra Nevada, Yosemite Valley to Plumas County; n. 1986, Hartweg).

10. C. LILACINUS, Kellogg. Stem bulbiferous near the base, with broad leaves and long conspicuous bracts: flowers 4 to 10, on long pedicels in 1 to 3 umbels, or subumbellate: petals pale lilac with

purplish claw, 6 to 12 lines long, somewhat hairy below the middle; gland ciliate-margined and with a narrow scale: anthers oblong (1 to 1½ lines long), obtuse: capsule elliptical, obtuse at each end, an inch long. — Proc. Calif. Acad. 2. 5; Baker, l. c. 306. *C. umbellatus*, Wood, l. c. 168. *C. uniflorus*, Hook. f. Bot. Mag. t. 5804. California (Coast Ranges, San Francisco to the Geysers).

11. C. UNIFLORUS, Hook. & Arn. Stem very short, bulbiferous, 1–2-flowered: bracts elongated: petals lilac with purplish claw, the lower half hairy above the small purple densely hairy gland: anthers obtuse, 2 lines long: capsule unknown. — Bot. Beechey, 398, t. 94; Baker, l. c. 306. *Cyclobothra*, Kunth. California (Coast Ranges, Monterey to Sonoma County).

* * Flowers open-campanulate, with usually densely hairy glands (without scales, except in n. 12); sepals often hairy or subglandular within: capsule (except in n. 12, 13) narrowly oblong and thick-lobed, acute, septicidal: seed-testa white, loose and spongy, minutely tessellated: pedicels stout, erect, and stems usually stouter and more strict. — § MARIPOSA, Wood.

+ Capsule as in § *Eucalychortus*: flowers large, lilac.

12. C. GREENEI. Stem stout, branching, 2–5-flowered, a foot high or more: leaf an inch broad: bracts elongated: sepals with a yellowish hairy spot; petals lilac, barred below with yellow and more or less of purple, and loosely covered with long hairs, rarely at all ciliate: gland deep, densely villous with long hairs above a broad transverse laciniate scale: anthers broad, acute or obtuse, 3 to 6 lines long: capsule an inch long, narrowed to a stout beak. — Siskiyou County, California (Rev. E. L. Greene); Multnomah County, Oregon (T. J. Howell).

13. C. NITIDUS, Dougl. Stem umbellately 1–3-flowered, shortly bracteate in the middle: leaf narrow: sepals naked; petals cream-colored with a lilac spot in the centre, sparingly hairy below; gland shallow, narrowly oval, densely covered with tangled yellow hairs, without scale: anthers acute, 2½ to 4 lines long: capsule round to broadly elliptical, 9 lines long, with short stout beak. — Hort. Trans. 7. 277, t. 9, f. A; Baker, l. c. 307. *Cyclobothra*, Kunth. *C. eurycarpus*, Watson, King's Rep. 5. 348. Oregon to N. E. Nevada.

+ + Capsule narrowly oblong, with thick obtusely angled lobes.

++ Flowers yellow or orange, more or less marked with brown or purple.

14. C. WEEDII, Wood. Corm fibrous-coated: stem leafy, 1–3-flowered: leaves convolute: sepals with a slightly hairy brown spot; petals deep yellow, dotted and often margined with purple, covered with slender hairs and ciliate, an inch long or more; gland small,

densely hairy: anthers acute, 4 to 6 lines long. — Proc. Philad. Acad. 1868, 169. *C. luteus*, var. *Weedii*, Baker, l. c. 309. *C. citrinus*, Baker, Bot. Mag. t. 6200. California (Coast Ranges, San Diego County and northward).

Var. PURPURASCENS. Petals purple or blotched with purple; gland somewhat larger. — Santa Barbara and Cajon Pass.

15. C. KENNEDYI, Porter. Stem 2–4-flowered, usually stout: sepals broad, with a purple spot; petals reddish-orange, not ciliate nor hairy, or only slightly so upon a broad deep-purple spot surrounding the densely hairy gland: anthers 4 lines long, on very short filaments. — Coulter's Bot. Gazette, 2. 79. Southern California (Fort Tejon to Providence Mountains).

16. C. LUTEUS, Dougl. Stem bulbiferous near the base, 1–6-flowered: leaves usually very narrow: sepals narrowly lanceolate, with a brown spot; petals an inch or two long, yellow to deep orange, lined with brownish purple especially on the middle third where it is usually slightly hairy; claw purplish; gland round or somewhat lunate, densely covered with ascending hairs: anthers yellow, obtuse, 2½ to 5 lines long: capsule 1 to 1½ inches long. — Lindl. Bot. Reg. t. 1567; Fl. Serres, t. 104, f. 2; Baker, l. c. 309. California (San Diego to Mendocino County and foothills of the Sierra Nevada). Frequent and very variable in color and markings, perhaps running into *C. venustus*.

Var. CITRINUS. The whole petal deep or lemon yellow, with a central circular or transverse brown spot. — *C. venustus*, var. *citrinus*, Baker, l. c.

Var. OCULATUS. Petals white, lilac or yellowish, with a similar dark central spot; gland usually narrowly lunate.

17. C. CLAVATUS. Distinct from the rest of the group in the strongly clavate hairs which cover the lower half of the petal: petals yellow tinged or lined with brown; gland deep, circular: anthers purple, obtuse, 4 or 5 lines long. — California (San Luis Obispo; J. G. Lemmon, 1878).

18. C. AUREUS, Watson. Very low: petals without hairs, yellow with a narrow crescent of purple bordering the rounded gland, which is densely covered with reflexed hairs. — Amer. Naturalist, 7. 303; Baker, l. c. 305. S. Utah.

↔ ↔ Flowers white or lilac.

19. C. VENUSTUS, Benth. Resembling *C. luteus*: petals white or pale lilac, with a more or less conspicuous reddish spot at top, a brownish yellow-bordered centre, and a brownish base; gland large, oblong,

usually densely hairy and surrounded by scattered hairs: capsule 1 to 2½ inches long. — Hort. Trans. 1. 412, t. 15, f. 3; Lindl. Bot. Reg. t. 1669; Fl. Serres, t. 104, f. 3; Regel, Gartenfl. t. 865; Baker, l. c. 310. California (from Alameda County southward); frequent and very variable.

Var. PURPURASCENS. Petals deep lilac or purplish, with similar markings.

20. C. SPLENDENS, Dougl. Like the last, but the petals clear lilac, paler below (the claw somewhat darker), with scattered white hairs below the middle, and with or without a round densely hairy gland: anthers purple, obtuse or acute, 3 to 6 lines long. — Benth. l. c., t. 15, f. 1; Lindl. Bot. Reg. t. 1676; Baker, l. c. 309. California (Monterey to San Diego).

21. C. FLEXUOSUS, Watson, l. c. Stem stout, more or less flexuous, branching, not bulbiferous: sepals shorter, obtusish; petals as in the last, usually slightly hairy or dotted around the brown or orange gland: anthers obtuse, 1½ to 3 lines long: capsule oblong, an inch long. — Baker, l. c. 306. S. Utah.

22. C. PALMERI. Stem very slender, lax and flexuous, a foot or two high, 1–7-flowered, bulbiferous near the base: sepals with narrowly acuminate recurved tips, spotted; petals 6 to 12 lines long, white (or yellowish below) with a brownish claw, and with scattered hairs around the ill-defined broad densely hairy gland: anthers obtuse, 3 lines long: capsule very narrow, an inch long or more. — California (near the Mohave River; n. 527, Palmer, 1876).

23. C. MACROCARPUS, Dougl. Stem erect and rigid, with 3 to 5 narrow short cauline leaves, 1- (rarely 2-) flowered: sepals acuminate, with sometimes a hairy spot; petals acute, 1½ to 2 inches long, purple-lilac, paler at base, with a greenish midvein, and somewhat villous above the oblong densely hairy gland: anthers acutish, 4 to 6 lines long. — Hort. Trans. 7. 275, t. 8; Lindl. Bot. Reg. t. 1152; Baker, l. c. 309. Washington Territory and Idaho to N. California. Peculiar in its habit.

24. C. NUTTALLII, Torr. & Gray. Stem slender, bulbiferous at base, with a single narrow cauline leaf (rarely 2 or 3), umbellately 1–5-flowered: sepals ovate-lanceolate, often with a dark or hairy spot; petals an inch or two long, white tinged with greenish yellow or lilac, with a purplish spot or band above the yellow base, and hairy around the circular or oblong gland: anthers obtuse, sagittate, 3 or 4 lines long. — Pacif. R. Rep. 2. 124; Baker, l. c. 306, excl. syn. *Fritillaria alba*, Nutt. Gen. 1. 222; Baker, l. c. 271. *Amblirion album*, Sweet,

C. luteus, Nutt. Journ. Acad. Philad. 7. 53. *C. Leichtlinii*, Hook. f. Bot. Mag. t. 5862; Baker, l. c. 310. California (Sierra Nevada, often dwarf and alpine) to Dakota, Colorado and New Mexico. A variable species, and of the widest range.

25. C. GUNNISONI, Watson. Resembling the last, but with acuminate anthers and a broad transverse gland: petals light lilac, yellowish-green below the middle, banded and lined with purple. — King's Rep. 5. 348; Baker, l. c. 310. Rocky Mountains, from Wyoming to New Mexico.

* * * Flowers open-campanulate, the glands naked or less densely hairy; sepals more or less pitted: capsule linear, acute, septicidal: upper leaves usually bulbiferous in the axils. Mexican. — § CYCLOBOTHRA, Baker. (*Cyclobothra*, Sweet.)

+ Stem 1–2-flowered, leafy: leaves dilated at base: flowers and fruit nodding: petals oblong-lanceolate.

26. C. HARTWEGI, Benth. Stem stout, a foot high or less: leaves narrow, elongated: sepals nearly equalling the petals, purplish with a darker spot at base; petals purplish with darker veins, and with long hairs on the margin and midvein, 18 lines long by 6 wide; gland dark, naked: anthers obtuse, 3 or 4 lines long, on elongated filaments: capsule with thin acutely angled lobes, 1½ inches long. — Pl. Hartw. 26; Baker, l. c. 307. *Cyclobothra*, Kunth. Aguas Calientes (n. 230, Hartweg).

27. C. BONPLANDIANUS, Schult. f. Similar, but the cauline leaves short and acuminate-lanceolate: sepals shorter than the petals, yellowish with a purple pit; petals purple, tinged with yellow, somewhat hairy and ciliate with short stiff hairs, 14 to 16 lines long; gland dark, naked. — Syst. Veg. 7. 1532. *Cyclobothra purpurea*, Sweet, Fl. Gard. 2 ser. t. 20. *C. purpureus*, Baker, l. c. 308, with syn., in part. Michoacan to Oaxaca.

28. C. FUSCUS, Schult. f. Corm fibrous-coated: flower smaller, erect or somewhat nodding: sepals slightly hairy within; petals 5 or 6 lines long by 2½ broad, naked excepting a dense cluster of yellow hairs on each side of the gland. — Syst. 7. 1534. "Arismendi" (Karwinsky). Probably a good species, judging from the description.

29. C. SPATULATUS. Resembling *C. Bonplandianus*: flowers purple; sepals and petals spatulate, with a dark hairy roundish gland at the summit of the narrow naked claw; petals 9 or 10 lines long, ciliate and covered with long scattered hairs. — Oaxaca (Ghiesbreght).

+- +- Stem usually branching, often tall: leaves narrowly linear, narrow at base: flowers small, nodding or erect, the pedicels erect in fruit: petals oblong-obovate, cuneate or rhombic.

30. C. FLAVUS, Schult. f. Corm fibrous-coated: flowers yellow: petals and sepals acute, rhombic-oblong, with a dark somewhat hairy gland; petals hairy and usually denticulate, 8 to 12 lines long: anthers 1½ or 2 lines long, shorter than the filaments: capsule 1 to 2 inches long. — Baker, l. c. 308, with syn. Guanajuato to Oaxaca.

31. C. GHIESBREGHTII. Flowers erect, white tinged with lilac, the sepals darkest: sepals and petals (6 to 8 lines long) with a somewhat hairy gland near the base; petals cuneate-obovate, obtuse, hairy below the middle: anthers 1½ lines long, little shorter than the filaments: capsule 1½ to 2 inches long. — Chiapas (n. 104, 661, Ghiesbreght).

* * * * Flowers unknown: capsule narrowly oblong, obtuse, loculicidally dehiscent at the summit: seed flat and horizontal in one row in each cell, with close white testa.

32. C. CATALINÆ. Stem 2 feet high, branching, from a small oblong-ovate corm: leaves and bracts very narrowly linear: ovary winged: capsule triangular, an inch or two long by 4 or 5 lines wide, very obtuse: seeds thin and very numerous, 2 lines in diameter; testa minutely pitted. — Santa Catalina Island (Paul Schumacher, June, 1878).

31. UVULARIA, Linn.

1. U. PERFOLIATA, Linn. Glaucous throughout: stem ½ to 1½ feet high, with 1 to 3 leaves below the fork: leaves glabrous, glaucous beneath, oblong- to ovate-lanceolate, acute: perianth-segments 8 to 16 lines long, granular-pubescent within: stamens shorter than the styles, the tip of the connective acuminate: ovary somewhat triquetrous; capsule broader than high, the cells with two prominent acute ridges and horn-like projections. — Smith, Exot. Bot. 1. 97, t. 49. Canada to Florida and Mississippi.

2. U. GRANDIFLORA, Smith. Yellowish-green, not glaucous: stem naked or with a single leaf below the fork: leaves whitish-pubescent beneath, usually somewhat acuminate: perianth-segments smooth within or nearly so, 12 to 18 lines long: stamens exceeding the styles, obtusely tipped: ovary obtusely triangular; capsule obtusely lobed. — Exot. Bot. 1. 99, t. 51; Ker, Bot. Mag. t. 1112. Canada to Iowa and south to Georgia. *U. flava*, Smith (l. c., t. 50), appears to differ only in its brighter yellow flowers.

32. OAKESIA.

1. O. SESSILIFOLIA. Stem a foot high or less, naked or with a single leaf below the fork, glabrous: leaves oblong-lanceolate, acute at each end, minutely scabrous on the margin, pale, glaucous beneath: flowers 7 to 12 lines long, smooth within: anthers obtuse, shorter than the style: capsule stipitate, 10 lines long. — *Uvularia sessilifolia*, Linn.; Smith, Exot. Bot. 1. 101, t. 52; Sims, Bot. Mag. t. 1402; Lodd. Bot. Cab. t. 1262. *U. Floridana*, Chapm. Flora, 487. Canada (New Brunswick, Quebec) to Florida and Arkansas.

2. O. PUBERULA. Branches usually somewhat scabrous: leaves firmer and darker green, ovate to lanceolate, mostly rounded at base, very rough on the margin: capsule sessile or nearly so, 10 to 12 lines long, brown-dotted. — *Uvularia puberula*, Michx.; Lodd. Bot. Cab. t. 1260; Sweet, Fl. Gard. 2 ser. t. 21. Virginia to South Carolina.

33. STREPTOPUS, Michx.

1. S. AMPLEXIFOLIUS, DC. Glabrous throughout, glaucous, 2 or 3 feet high: leaves cordate at base, the margin rarely slightly scabrous: flowers greenish-white, 4 to 6 lines long: anthers cuspidate with a single slender awn: stigma scarcely lobed: berry thin-coated; cells 10–14-seeded. — *Uvularia amplexifolia*, Linn.; Hornem. Fl. Dan. t. 1515. *S. distortus*, Michx. *S. amplexicaulis*, Poir.; Baker, Journ. Linn. Soc. 14. 591. Alaska to N. California and across the continent, ranging south to New Mexico and Pennsylvania; also in temperate Europe and Asia.

2. S. ROSEUS, Michx. Lower and somewhat pubescent: leaves less cordate or only clasping, scabrous-ciliate: pedicels often all sessile (i. e. not geniculate upon a peduncle): flowers rose-purple, 3 or 4 lines long: anthers bicuspidate: stigma 3-cleft: berry with a rather thicker coat, the cells 6–8-seeded. — Fl. 1. 201, t. 18; Lodd. Bot. Cab. t. 1603; Baker, l. c. 592. *Uvularia rosea*, Pers.; Ker, Bot. Mag. t. 1489. *Hekorima rosea*, Raf. Alaska to Oregon and Canada (Labrador) and south to Georgia. Eschscholtz's specimens collected at Sitka and referred to *Kruhsea Tilingii*, Regel (*Smilacina streptopoides*, Ledeb.), belong to this species. On the other hand, the *S. roseus* of Wright's collection in Ochotsk Sea is the same as Tiling's plant (from the same locality) upon which *Kruhsea* was founded, but is properly a *Streptopus* (i. e. *S. Ajanensis*, Tiling).

3. S. BREVIPES, Baker, l. c. Glabrous throughout, very low and with very slender creeping rootstock: leaves not at all cordate nor

ciliate: fruit on pedicels 3 or 4 lines long, the cells 2–8-seeded. — Cascade Mountains, Washington Territory (Lyall); known only in fruit. Perhaps a reduced form of the last.

34. PROSARTES, D. Don.

* Stigma 3-cleft: leaves rarely cordate at base.

+ Perianth very broad and gibbously truncate at base.

1. P. Menziesii, Don. More or less woolly-pubescent: leaves ovate to ovate-lanceolate, narrowly acuminate or the lowest acute, often resinous-dotted: perianth-segments nearly erect, acute, 6 to 11 lines long: stamens a third shorter: style usually somewhat woolly: ovary nearly glabrous: capsule oblong-obovate, attenuate to a short subvillous beak; cells 1–2-seeded. — Linn. Trans. 18. 533; Baker, Journ. Linn. Soc. 14. 587. *Uvularia Smithii*, Hook. Fl. Bor.-Am. 2. 174, t. 189. California (Mendocino County) to British Columbia.

+ + Perianth narrower and more cuneate at base.

2. P. lanuginosa, Don, l. c. Woolly-pubescent: leaves oblong-lanceolate, narrowly acuminate: perianth-segments greenish, linear-lanceolate, acuminate, spreading, 6 or 7 lines long: stamens a third shorter: style and narrow ovary glabrous: capsule oblong-ovate, obtusish or with a very short stout beak, glabrous; cells 1–2-seeded. — Baker, l. c. 586, excl. vars. *Streptopus*, Michx. *Uvularia*, Pers.; Ker, Bot. Mag. t. 1490. Western New York to Georgia and Tennessee.

3. P. maculata, Gray. Pubescent: leaves oblong-lanceolate, acuminate: perianth-segments yellowish white, with purple dots, very narrow at base, lanceolate above and acute, 8 to 10 lines long, scarcely exceeding the stamens: style glabrous: ovary ovate, villous, with a single pair of ovules in each cell. — Amer. Journ. Sci. 2 ser. 47. 201. *Streptopus maculatus*, Buckley, same, 45. 170. Mountains of Tennessee and North Carolina.

4. P. trachycarpa, Watson. More or less pubescent: leaves ovate to oblong-lanceolate, acute or rarely acuminate: perianth-segments whitish, slightly spreading, narrowly oblanceolate, acute, 4 to 6 lines long, about equalling the stamens: ovary broad: fruit broadly obovate, obtuse and rather deeply lobed, papillose; cells 2–6-seeded. — King's Rep. 5. 344; Baker, l. c. Saskatchewan to N. Idaho, Utah and Colorado.

* * Stigma entire: leaves mostly cordate-clasping.

5. P. Hookeri, Torr. More or less rough-pubescent with short

usually spreading hairs: leaves ovate or sometimes oblong, acute or shortly acuminate: perianth usually rather broad at base, spreading; segments acute, 5 or 6 lines long, about equalling the stamens: ovary narrow, more or less pubescent; style glabrous: fruit obovate, obtuse; cells usually 2-seeded. — Pacif. R. Rep. 4. 144. *P. lanuginosa*, var. *Hookeri*, Baker, l. c. California (Coast Ranges, Marin County to Santa Cruz).

6. P. TRACHYANDRA, Torr. l. c. Resembling the last: leaves less deeply cordate, the upper ones often not at all so, and broader toward the apex: stamens a third shorter than the perianth; anthers minutely hispid: ovary glabrous: fruit glabrous, with a short stout beak. — *P. lanuginosa*, var. *trachyandra*, Baker, l. c. California (Sierra Nevada, from Tuolumne to Plumas County).

7. P. OREGANA. More or less woolly-pubescent: leaves ovate to oblong-lanceolate, long-acuminate: perianth-segments spreading, acute, narrowed below, very distinctly net-veined, 5 to 7 lines long, equalling or shorter than the stamens: fruit ovate, acutish, somewhat pubescent; cells 1–2-seeded. — *Uvularia lanuginosa*, var. *major*, Hook. Fl. Bor.-Am. 2. 174. Oregon and Idaho to British Columbia.

35. CLINTONIA, Raf.

* Ovules a single pair in each cell: flowers small, umbellate.

1. C. UMBELLATA, Torr. Inflorescence villous-pubescent or glabrous: flowers 10 to 20 or more, suberect on slender pedicels, white with often a green or purplish spot at the tips; segments broadly spatulate, 3 or 4 lines long, about equalling the stamens: style slender: fruit small. — Fl. N. York, 2. 301; Baker, Journ. Linn. Soc. 14. 584. *Convallaria umbellulata*, Michx. *Smilacina umbellata*, Desf. Ann. Mus. 9. 53, t. 8. *S. borealis*, Ker, Bot. Mag. t. 1155. *Convallaria umbellata*, Poir. *Maianthemum*, Link. *C. multiflora*, Beck. New York to Georgia in the Alleghanies.

* * Ovules several pairs in each cell: flowers larger.

+- Flowers umbellate.

2. C. BOREALIS, Raf. Inflorescence woolly-pubescent or glabrate: flowers (3 to 6) nodding, greenish yellow; segments oblanceolate, 6 to 8 lines long: filaments pubescent or glabrous: style stout: fruit 3 or 4 lines in diameter; cells 6–8-seeded. — Baker, l. c. *Dracæna borealis*, Ait. Hort. Kew, 1. 454, t. 5; Andr. Bot. Rep. t. 206. *Smilacina borealis*, Ker, Bot. Mag. t. 1403. Labrador to Winnipeg Valley, south to N. Carolina.

3. C. ANDREWSIANA, Torr. Scape a foot or two high, usually with a foliaceous bract and one or more few-flowered lateral fascicles: inflorescence more or less pubescent; terminal umbel many-flowered; pedicels slender: flowers suberect, deep rose-color; segments oblanceolate, gibbous at base, 4 to 7 lines long, exceeding the stamens and style: filaments pubescent: fruit 4 or 5 lines long; cells 8–10-seeded. — Pacif. R. Rep. 4. 150; Baker, l. c. California (Coast Ranges, Humboldt County to Santa Cruz).

+- +- Flower solitary.

4. C. UNIFLORA, Kunth. More or less villous-pubescent throughout: scape mostly shorter than the leaves, usually with a very small bract: flower (rarely 2) white, pubescent, suberect; segments broadly oblanceolate, 9 to 12 lines long, exceeding the stamens: filaments pubescent: fruit 4 to 6 lines long; cells 6–10-seeded. — Baker, l. c. *Smilacina uniflora*, Menz.; Hook. Fl. Bor.-Am. 2. 175, t. 190. California (Calaveras and Humboldt Counties) to British Columbia.

36. SCOLIOPUS, Torr.

1. S. BIGELOVII, Torr. Leaves oval-elliptic to narrowly oblanceolate, 4 to 15 inches long, sessile or narrowed at base: pedicels (3 to 12) 3 to 8 inches long: outer perianth-segments several-nerved, the inner 3-nerved, 7 to 9 lines long: ovary linear-oblong; stigmas 2 lines long: capsule light-colored, 9 to 14 lines long, beaked by the stout style (2 or 3 lines long): seeds 1 to 1½ lines long. — Pacif. R. Rep. 4. 145, t. 22. California (Coast Ranges, Marin to Humboldt County).

2. S. HALLII. Leaves smaller (3 to 5 inches long), somewhat petioled: pedicels very slender, 2 inches long or less: ovary broader; style more slender and stigmas only a line long: capsule brown-purple, 5 lines long: rootstock and roots more slender. — *S. Bigelovii*, Gray, Proc. Amer. Acad. 8. 404. Oregon (Cascade Mountains, Hall). Flower unknown.

37. MEDEOLA, Gronov.

1. M. VIRGINIANA, Linn. Stem a foot or two high, floccose-woolly becoming glabrate: leaves oblong-lanceolate or uppermost ovate, acuminate, 5 to 9 in the lower whorl, 2 to 4 in the upper, nearly sessile: pedicels (3 to 10) slender, an inch long or less: perianth-segments 3 or 4 lines long, exceeding the stamens, shorter than the purple stigmas: berry 2 or 3 lines in diameter; cells usually

1-seeded. — Lam. Ill. t. 266, f. 2; Ker, Bot. Mag. t. 1316; Meehan, Nat. Fl. 2. 157, t. 40. *Gyromia Virginica*, Nutt. Canada to Florida and Arkansas.

38. TRILLIUM, Linn.

* Ovary and fruit 6-angled and more or less winged. (Mature fruit very imperfectly known.)

+- Flowers sessile: the broad connective produced beyond the anther-cells.

1. T. SESSILE, Linn. Leaves sessile, broadly ovate or rhomboidal, acute, somewhat cuneate or sometimes broadly rounded at base, 1½ to 5 inches long: sepals spreading: petals narrowly lanceolate to oblanceolate, acute or acutish, ½ to 3 inches long, brown-purple or rarely greenish-white: stamens erect, usually exceeding the stout suberect stigmas; filaments 1½ lines long or less. — Curt. Bot. Mag. t. 40; Lodd. Bot. Cab. t. 875; Fl. Serres, t. 2311. *T. viride*, Beck. *T. discolor* (?), Chapman, Flora, 478. Pennsylvania to Wisconsin, south to Florida and Alabama.

Var. WRAYI. Petals spatulate, obtuse, greenish, an inch long. — *T. discolor*, Wray; Hook. Bot. Mag. t. 3097. Georgia.

Var. NUTTALLII. Upper stem and nerves of the leaves beneath rough-pubescent: petals linear-lanceolate, purplish-green with brown base, 2 inches long. — *T. viridescens*, Nutt. Trans. Amer. Phil. Soc. 2. 5. 155. Arkansas.

Var. CALIFORNICUM. Stouter: leaves broadly rhombic-ovate, 3 to 6 inches long: petals oblanceolate to rhombic-obovate, 1 to 4 inches long, purple or rose-color or white: anthers 6 to 9 lines long, usually considerably exceeding the stigmas. — Vars. *giganteum* and *chloropetalum*, Torr. in Pacif. R. Rep. 4. 151. California (San Luis Obispo northward) to Oregon.

Var. ANGUSTIPETALUM, Torr. l. c. Similar, but the leaves somewhat petiolate; petals narrowly oblanceolate to linear. — Var. *giganteum*, Hook. & Arn. Bot. Beechey, 402. California to Oregon; less frequent.

2. T. RECURVATUM, Beck. Leaves petioled, ovate to ovate-oblong, usually acute at both ends: sepals reflexed: petals oblong-lanceolate, narrowed to a claw at base, 9 to 18 lines long, brown-purple: stamens incurved, much exceeding the stigmas; filaments 2 or 3 lines long. — Am. Journ. Sci. 11. 178. *T. unguiculatum*, Nutt. l. c. Wisconsin to Indiana and Arkansas.

Var. (?) LANCEOLATUM. Leaves sessile, more narrowly lanceolate: sepals less strictly reflexed; petals more narrowly lanceolate or nearly

linear, with longer claws: filaments longer. — *T. lanceolatum*, Boykin in herb. Torr. Georgia and Alabama.

3. T. PETIOLATUM, Pursh. Stem very short, scarcely exserted from the basal sheaths: leaves ovate-elliptic to reniform, 3 to 5 inches long, with petioles as long or longer: sepals erect; petals purple, narrowly oblanceolate, an inch or two long: stamens with short filaments, exceeding the slender stigmas. — Hook. Fl. Bor.-Am. 2. 180, t. 192. Idaho, Oregon and Washington Territory.

+- +- Flowers pedicellate: connective not produced.

++ Pedicel longer than the flower: filament shorter than the anther: leaves sessile or nearly so.

4. T. ERECTUM, Linn. Leaves very broadly rhombic, 2½ to 6 inches wide, shortly acuminate: pedicel usually more or less inclined or declinate: petals ovate to lanceolate, 9 to 18 lines long, brown-purple or often white or greenish or pinkish: stamens equalling or exceeding the stout distinct spreading or recurved stigmas. — Curt. Bot. Mag. t. 470, 1027, 3250; Lodd. Bot. Cab. t. 1838, 1850. *T. rhomboideum*, Michx., excl. var. *grandiflorum*. *T. fœtidum*, Salisb. Parad. t. 35. *T. pendulum*, Willd. Hort. Berol. t. 35; Regel, Gartenfl. t. 656. *T. purpureum*, Kinn. From Canada (Nova Scotia to Winnipeg Valley) to N. Carolina, Tennessee and Missouri. It is probably *T. obovatum*, Pursh, as respects his Canadian plant, and it is apparently also the plant of E. Siberia. The Japanese form is distinguished by a somewhat produced connective and very short stigmas.

5. T. GRANDIFLORUM, Salisb. Leaves less broadly rhombic-ovate, 1½ to 3 or 4 inches wide: pedicel erect or ascending: petals oblanceolate, often broadly so, 1½ to 2½ inches long, white turning rose-color or marked more or less with green: stamens with slender filaments and anthers, exceeding the very slender erect or suberect and somewhat coherent stigmas. — Parad. t. 1; Lodd. Bot. Cab. t. 1349; Regel, Gartenfl. t. 575. *T. rhomboideum*, var. *grandiflorum*, Michx. *T. erythrocarpum*, Curt. Bot. Mag. t. 855. Vermont to N. Carolina, west to Wisconsin and Kentucky. Sports occur with petiolate leaves or naked stems.

6. T. OVATUM, Pursh. Closely resembling the last; petals lanceolate or more narrowly oblanceolate; stigmas somewhat stouter and more recurved. — *T. obovatum*, Hook. Fl. Bor.-Am. 2. 180. *T. Californicum*, Kellogg, Proc. Calif. Acad. 2. 50, f. 2. From British Columbia southward in the Coast Ranges to Santa Cruz, California.

++ ++ Pedicel short: filament slender, about equalling the anther.

= Pedicel recurved or strongly declinate.

7. T. CERNUUM, Linn. Leaves sessile or nearly so, very broadly rhombic-ovate, 2 to 4 inches broad: petals white, ovate-lanceolate, 6 to 12 lines long: stamens with short anthers, shorter than the stout recurved distinct stigmas: fruit ovate, 3-beaked.—Curt. Bot. Mag. t. 954. British America (Newfoundland to Mackenzie River) to Georgia.

8. T. STYLOSUM, Nutt. Leaves ovate-lanceolate, acute at each end and shortly petiolate, 2 to 4 inches long: petals rose-colored, oblong, acute, strongly curved and undulate, 9 lines to 2 inches long: stamens much exceeding the slender somewhat united stigmas: fruit oblong, with a stout beak. — *T. nervosum* and *Catesbæi*, Ell. N. Carolina to Florida.

= = Pedicel erect. (Doubtful species.)

9. T. PUSILLUM, Michx. Stem 6 to 8 inches high: leaves sessile, lanceolate or oblong, obtuse, 1½ to 2 inches long: petals lanceolate, acutish, pale flesh-color, 8 to 10 lines long: sepals obtuse: stigmas slender, united below. — Chapm. Flora, 478. Pine-barrens of North and South Carolina. The description of *T. Texanum*, Buckl. (Proc. Acad. Philad. 1860, 443), from N. E. Texas, is essentially the same. Both plants are known only from the descriptions.

* * Ovary and fruit 3-lobed or angled, not winged: flowers pedicelled: leaves petiolate: the slender filaments about equalling the anthers.

10. T. NIVALE, Riddell. Low: leaves ovate to lanceolate, obtuse, an inch or two long: pedicel erect or declined, short: petals oblong or oblanceolate, obtuse or acutish, 6 to 15 lines long, white: stamens usually shorter than the long slender stigmas: fruit depressed globose, with 3 rounded lobes, 3 or 4 lines long. — Syn. Fl. W. States, 93. Western Pennsylvania to Kentucky, Iowa and Wisconsin.

11. T. ERYTHROCARPUM, Michx. Leaves ovate, acute or acuminate, 2 to 6 inches long: pedicel erect or inclined, often exceeding the flower: petals oblanceolate, often broad, acute or acuminate, wavy, white with purplish base, an inch long: stamens about equalling the very slender stigmas: ovary 3-angled: fruit broad-ovate, obtuse, 7 to 9 lines long.—Sweet, Fl. Gard. t. 212; Lodd. Bot. Cab. t. 1232; Hook. Bot. Mag. t. 3002. *T. undulatum*, Willd. *T. pictum*, Pursh. New Brunswick to Wisconsin and Georgia, on high mountains or in cold damp woods.

39. MELANTHIUM, Linn.

* Perianth-segments with a conspicuous double gland at the summit of the claw.

1. M. Virginicum, Linn. Stem 3 to 5 feet high, leafy, rather slender: leaves linear, 4 to 10 lines wide, only the lowest sheathing: perianth-segments flat, ovate to oblong or slightly hastate, 2½ to 4 lines long: capsule ovate, half an inch long: seeds 10 in each cell, 2 or 3 lines long. — *M. Virginicum* and *monoicum*, Walt. *M. polygamum*, Desrouss. *Leimanthium Virginicum*, Willd. *Helonias*, Sims, Bot. Mag. t. 985. *Veratrum*, Ait. f. *Zygadenus*, Endl. *M. biglandulosum*, Bertol. Bot. Misc. 10. 34. From Canada to Carolina and Texas.

2. M. latifolium, Desrouss. Leaves more oblanceolate, often 2 inches broad: perianth-segments undulate, 2 or 3 lines long, the very narrow claw nearly equalling the orbicular or ovate blade: capsule 6 to 8 lines long; styles more slender: seeds 4 to 8 in each cell, 3 or 4 lines long. — Lam. Dict. 4. 25. *M. hybridum*, Walt.? *M. racemosum*, Michx. *Leimanthium hybridum*, Schult. f. *Zygadenus hybridus*, Endl. Connecticut to South Carolina. The identity of Walter's *M. hybridum* is doubtful.

* * Gland wanting: perianth-segments oblanceolate.

3. M. parviflorum. Stem rather slender, 2 to 5 feet high, sparingly leafy: leaves oval to oblanceolate (2 to 4 inches wide), on long petioles, only the lowest sheathing: perianth-segments oblanceolate or spatulate, 2 or 3 lines long, attenuate at base: stamens very short: capsule half an inch long; seeds 4 to 6 in each cell, 4 lines long. — *Veratrum parviflorum*, Michx.; Gray, Manual, 525. *Leimanthium monoicum*, Gray, Melanth. 116. *Zygadenus monœcus*, Kunth. Alleghanies (Virginia to S. Carolina).

40. VERATRUM, Tourn.

* Stem slender, sparingly leafy; leaves oblanceolate, only the lowest sheathing: flowers greenish purple; segments entire: ovary tomentose, soon glabrate: capsule ovate, acute, the cells few-seeded.

1. V. Woodii, Robbins. Stem slender, 2 to 5 feet high, sparingly leafy: leaves oblanceolate, 1 or 2 inches broad or more, on long petioles: panicle very narrow: pedicels 2 lines long or less, somewhat longer in fruit: perianth-segments nearly glabrous, oblanceolate, 3 or 4 lines long: stamens a little shorter, reddish: capsule a half-inch long. — Wood, Class-Book, 2 ed. 557; Gray, Manual, 526. Indiana to Missouri.

2. V. INTERMEDIUM, Chapman. Apparently very similar to the last: leaves narrower: panicle more open and slender: pedicels slender, 3 or 4 lines long, about equalling the flowers: perianth pubescent: fruit unknown. — Flora, 489. Middle Florida.

* * Stem stout, very leafy, the leaves broad-elliptical and sheathing: flowers yellowish-green or whitish, the segments serrulate or entire: ovary glabrous: capsule oblong-ovate, acute, many-seeded.

3. V. VIRIDE, Ait. Stem 2 to 7 feet high: leaves acute, the uppermost lanceolate and acuminate: branches of the simple panicle slender and more or less drooping: bracts foliaceous, lanceolate, usually nearly equalling the flowers: perianth greenish, adnate to the attenuate base of the capsule; segments oblanceolate, ciliate-serrulate, 4 to 6 lines long: stamens 2 or 3 lines long: capsule an inch long. — Bigel. Med. Bot. 2. 121, t. 33. *Melanthium bracteolare*, Desr. *Helonias viride*, Ker, Bot. Mag. t. 1096. *V. parviflorum*, Bong. *V. Eschscholtzii*, Gray. Georgia to Canada, and thence to Washington Territory and Alaska.

4. V. CALIFORNICUM, Durand. Similar: upper leaves lanceolate, but rarely acuminate: branches of the sometimes compound panicle ascending: bracts ovate-lanceolate, submembranous, usually little exceeding the pedicels: perianth-segments broader, obtuse, whitish with greener base, often denticulate above, 3 to 8 lines long, slightly adnate to the capsule: stamens 3 to 5 lines long: capsule an inch long or more. — Journ. Philad. Acad. 3. 103. *V. album*, auth. Colorado and Wyoming to N. California and Oregon.

* * * Stem stout and leafy; leaves oblong to lanceolate, mostly sheathing: perianth-segments fimbriate, somewhat biglandular: capsule obovate, obtuse, few-seeded.

5. V. FIMBRIATUM, Gray. Leaves narrowed at base, 6 to 18 inches long by 2 to 6 wide or more, acute or acuminate: branches of the panicle spreading: bracts ovate: perianth-segments rhombic-ovate, 3 to 5 lines long: capsule depressed and somewhat emarginate, 4 lines long: seeds oblong, scarcely winged. — Proc. Amer. Acad. 7. 391. California (Mendocino County).

41. STENANTHIUM, Gray.

1. S. ANGUSTIFOLIUM, Gray. Stem leafy, 3 or 4 feet high, very slender: leaves 2 or 3 lines broad: panicle elongated, nearly simple, very open; branches slender and flexuous: flowers polygamous or subdiœcious, nearly sessile or the fertile on short pedicels; peri-

anth-segments spreading, linear-lanceolate, 2 or 3 lines long: capsule strongly reflexed, narrowly oblong-ovate, 3½ lines long including the turbinate base, with spreading beaks: seeds angled, not margined, 2 to 2½ lines long. — Am. Journ. Sci. 42. 46, and Manual, 525. *Helonias graminea*, Sims, Bot. Mag. t. 1599. *Veratrum angustifolium*, Pursh; Gray, Rev. Melanth. 120. *Xerophyllum gramineum*, Nutt. Gen. 1. 235. Alleghanies, from Virginia to S. Carolina.

2. S. ROBUSTUM. Resembling the last: stem stout, leafy, 3 to 5 feet high, erect: leaves 4 to 10 lines broad: panicle or raceme often 2 feet long, frequently compound with numerous slender branches: perianth-segments 3 or 4 lines long, white or green: capsule erect, ovate, 4 lines long, with recurved beaks: seeds (immature) somewhat longer. — Pennsylvania to Ohio, Tennessee and South Carolina. It has been ordinarily included in the last.

3. S. OCCIDENTALE, Gray. Stem slender, a foot or two high, sparingly leafy: leaves linear to oblanceolate (3 to 12 lines wide): raceme simple or branched at base: flowers all perfect, campanulate, greenish-purple, 4 to 7 lines long, about equalling the pedicels; segments linear-lanceolate, with recurved tips: capsules at length erect, 6 to 8 lines long, attenuate into the elongated slender styles: seeds linear, flat and winged, 3 or 4 lines long. — Proc. Amer. Acad. 8. 405. Oregon to British Columbia. A Mexican species, S. FRIGIDUM, Kunth (*Veratrum*, Cham. & Schlecht.), tall, with large purple flowers and conspicuous bracts, seems rightly referred to this genus.

42. ZYGADENUS, Michx.

* Glands 2, orbicular, above the broad claw: root rhizomatous: flowers perfect.

1. Z. GLABERRIMUS, Michx. Stem 2 to 4 feet high, leafy: leaves 2 to 6 lines broad: panicle broad, with ovate greenish bracts: perianth adnate to the base of the ovary: segments 6 lines long, oblong-lanceolate; glands conspicuous: seeds linear, scarcely margined, 2½ lines long. — Fl. 1. 214, t. 22. *Helonias bracteata*, Sims, Bot. Mag. t. 1703; Lodd. Bot. Cab. t. 1330. *Helonias glaberrima*, Link. Virginia to Florida and Alabama.

* * Gland covering more or less of the base of the perianth-segments: bulb ovate; coats membranous.

+- Flowers rather large, mostly perfect.

2. Z. ELEGANS, Pursh. Stem ½ to 3 feet high: leaves glaucous, 2 to 6 lines broad: raceme simple or sparingly branched below, often

few-flowered: bracts ovate-lanceolate, usually purplish: perianth adnate at base; segments broad, greenish, 4 or 5 lines long, the inner abruptly contracted to a broad claw; gland obcordate: styles about 2 lines long or more: seeds oblong, angular, not margined, 2 lines long. — *Helonias glaberrima*, Ker, Bot. Mag. t. 1680. *Z. glaucus*, Nutt.; Lindl. Bot. Reg. 24, t. 67. *Z. chloranthus*, Richards. *Z. commutatus*, Schult. *Anticlea glauca*, Kunth. From Canada (New Brunswick) and Illinois to Oregon and Behring Straits; southward in the mountains to New Mexico and Nevada.

3. Z. Fremontii, Torr. Very similar, but less glaucous: leaves an inch broad or less: bracts mostly green: perianth free from the ovary, 3 to 7 lines long; gland irregular and notched on its upper margin: styles short (about 1 line long): capsule longer (6 to 12 lines): seeds shorter. — Pacif. R. Rep. 7. 20 (as *Z. Douglasii*). *Anticlea Fremontii*, Torr. in same, 4. 144. California (Coast Ranges, San Diego to Humboldt County).

4. Z. Nuttallii, Gray. Stem stout, 2 feet high: leaves 3 to 8 lines broad: racemes simple or rarely panicled, rather densely flowered, with narrow membranous bracts: perianth free from the ovary; segments 3 to 5 lines long, not unguiculate, with an ill-defined gland at base: stamens free: capsule half an inch long: seeds large (3 lines long), usually flattened. — Manual, 525. *Amianthium Nuttallii*, Gray, Rev. Melanth. 123, excl. var. β. *Amiantanthus Nuttallii*, Kunth. Texas to Colorado.

+ + Flowers smaller, polygamous.

5. Z. venenosus. Stem slender, ½ to 2 feet high: leaves rarely over 2 or 3 lines broad, scabrous, the cauline not sheathing: raceme simple, short, with narrow scarious bracts: perianth free from the ovary; segments triangular-ovate to elliptical, obtuse or rarely acutish, 2 or 3 lines long, all abruptly contracted to a short glandular claw, the blade rounded or subcordate at base; gland extending slightly above the claw with a well-defined irregular margin: stamens somewhat adnate to the claw: pedicels suberect in fruit: capsule 4 to 6 lines long: seeds 1½ to 2½ lines long. — California (Monterey and Mariposa Counties) to British Columbia and east to Utah and Idaho. Bulb poisonous. The Coast Range form is usually stouter, with a larger occasionally compound raceme. Hitherto referred to the last species.

6. Z. paniculatus, Watson. Very similar: usually stout: leaves 3 to 8 lines broad, usually all sheathing: raceme compound: perianth-

segments deltoid, acute or acuminate, with a short claw; gland less definitely margined, often reaching nearly to the middle of the blade: fruiting pedicels spreading: capsule ½ to 1 inch long: seeds 3 to 5 lines long. — King's Rep. 5. 344. *Amianthium Nuttallii*, var. β, Gray, Rev. Melanth. 121. *Helonias paniculata*, Nutt. Journ. Philad. Acad. 7. 57. California (east slope of Sierra Nevada) and Idaho to Utah and the Sackatchewan.

* * * Gland obscure or almost wanting: perianth small, rotate or reflexed: bulb narrow; coats becoming fibrous.

7. Z. LEIMANTHOIDES, Gray. Stem leafy, 1 to 4 feet high, from a narrow oblong bulb: leaves 2 to 4 lines broad: racemes panicled, rather dense and many-flowered: perianth-segments oblong, not unguiculate, 2 lines long, adherent to the base of the ovary, white becoming greenish or purplish: capsule 4 lines long, the cells slightly divergent at top: seeds 4 in each cell, 3 lines long, somewhat margined below. — Manual, 525. *Amianthium*, Gray, Rev. Melanth. 125. *Amiantanthus*, Kunth. New Jersey to Georgia.

8. Z. ANGUSTIFOLIUS. Resembling the last: leaves 2 or 3 lines broad: raceme simple: perianth free from the ovary: capsule more oblong (5 lines long), the cells not at all divergent: seeds about 4 lines long. — *Helonias*, Michx. *Amianthium*, Gray, l. c. 124; Chapm. Flora, 490. *Amiantanthus*, Kunth. N. Carolina to Florida and Alabama.

Two Mexican species are described, viz.: Z. VOLCANICUS, Benth. (Pl. Hartw. 96), with elongated grass-like leaves, a rather tall slender leafy stem, and flowers (3 lines long) on long divaricate pedicels in open lax panicled racemes, the perianth adnate to the base of the capsule; and the quite doubtful *Helonias virescens*, HBK. (*Anticlea Mexicana*, Kunth), described as low, with a very short somewhat branched raceme of very small whitish flowers. But for the branching raceme it might be suspected of belonging to *Schœnocaulon*. The *Zygadenus Sibiricus*, Gray (*Anticlea*, Kunth), should probably be referred to *Stenanthium*, though the segments are glandular.

43. SCHŒNOCAULON, Gray.

1. S. GRACILE, Gray. Scape very slender, 2 or 3 feet high: leaves a line or two wide: flowers green, at length scattered in a spike 4 to 6 inches long; segments narrowly oblong, a line long or less: filaments very slender: capsule nearly sessile, 4 lines long or more; cells about 7-seeded. — Rev. Melanth. 127. *Helonias* (?) *dubia*, Michx. Southern Georgia to Florida.

2. S. Drummondii, Gray. Stouter, 1 to 3 feet high: leaves 1 to 3 lines broad: flowers green, in a spike-like raceme 4 to 8 inches long; segments narrowly oblong-lanceolate, 1½ lines long: filaments stout, subclavate-filiform: fruiting pedicels a line long: capsule erect, narrow, a half-inch long; cells 4–6-seeded. — Bot. Beechey, 388. *S. Texanum*, Scheele, Linnæa, 25. 262. Texas.

Mexican Species.

3. S. caricifolium, Gray. Scape stout, a span high, much shorter than the very narrow flexuous leaves: flowers green, in a raceme 2 inches long; segments oblanceolate, 1½ lines long: filaments rather slender: fruiting pedicels a line long: capsule ovate, a half-inch long: seeds large, 2 in each cell. — Bot. Beechey, 388. *Veratrum*, Schlecht. Ind. Sem. Hal. 1838 (Linnæa, Litt.-Ber. 1839, 100). Coulter, n. 1568; Gregg, n. 214?

4. S. officinale, Gray, l. c. Scape 2 to 4 feet high: leaves 4 to 6 lines broad: raceme dense, becoming 6 to 18 inches long: flowers nearly white; segments 1½ lines long, narrowly oblong: filaments stout: fruiting pedicels 2 lines long: capsule ovate-oblong; cells 2–4-seeded. — *Veratrum*, Schlecht. *Helonias*, Don. *Asagræa*, Lindl. Mexico to Venezuela. There appear to be some other unnamed species, allied to *S. Drummondii* and *caricifolium*.

44. AMIANTHIUM, Gray.

1. A. muscætoxicum, Gray. Stem 1½ to 4 feet high: leaves shorter, 3 to 15 lines broad: raceme oblong-pyramidal, 2 to 4 inches long; pedicels 4 to 8 lines long, with short ovate membranous bracts: perianth-segments spreading, 2 lines long, equalling the slender filaments: capsule broader above than long (scarcely 3 lines): seeds 1 to 1½ lines long. — Rev. Melanth. 122, with syn. *Melanthium*, Walt. *M. densum*, Desr.; Lam. Ill. t. 269, f. 3. *Helonias læta*, Ker, Bot. Mag. t. 803, 1540; Lodd. Bot. Cab. t. 998. *H. erythrosperma*, Michx. New Jersey to Florida, Kentucky and Arkansas.

45. HELONIAS, Linn.

1. H. bullata, Linn. Stem stout, 1 to 2 feet high, leafy and sheathed with broad bracts at base, and with small submembranous bracts above: leaves numerous, evergreen, 6 to 12 inches long: raceme an inch or two (becoming 4 to 6 inches) long: perianth-segments 3 lines long, about equalling the pedicels and capsules: seeds 2 lines

long. — Curt. Bot. Mag. t. 747; Andr. Bot. Rep. t. 352; Lodd. Bot. Cab. t. 961; Meehan, Nat. Fl. 1. 33, t. 9. *H. latifolia*, Michx. N. Jersey to Virginia.

46. CHAMÆLIRIUM, Willd.

1. C. CAROLINIANUM, Willd. Stem 1 to 4 feet high: lower leaves spatulate-oblanceolate, 2 to 6 inches long, the cauline narrower: raceme often a foot long or more; the staminate with slender pedicels 1 to 3 lines long, the fruiting pedicels stouter and more scattered: capsule 4 to 6 lines long: seed about 3 lines long. — *Veratrum luteum*, Linn. *Helonias pumila*, Jacq. Icon. Rar. t. 253. *H. lutea*, Ait. f.; Ker, Bot. Mag. t. 1062. *Helonias dioica*, Pursh; Gray, Rev. Melanth. 132, with syn. *Chamælirium luteum*, Gray, Manual, 527. Canada to Georgia, and west to Nebraska and Arkansas.

47. TOFIELDIA, Huds.

* Glabrous; infloresence centrifugal: pedicels mostly solitary: seeds not appendaged.

+ Dwarf, mostly arctic or alpine: raceme short, few-flowered.

1. T. PALUSTRIS, Huds. Stem naked and scape-like, 2 to 6 inches high: leaves ½ to 1½ inches long by about a line broad: raceme subglobose or from 6 to 12 lines long in fruit: pedicels minutely involucrate at the very base, a line long in fruit: perianth-segments spatulate, two thirds of a line long, shorter than the round-ovate capsule: seeds oblong, quadrangular, ½ line long. — *T. borealis*, Wahl. *Narthecium pusillum*, Michx. Lake Superior, Rocky Mountains of British America and to Greenland: Europe.

2. T. COCCINEA, Richards. Similar, but the stem (an inch or two high) with usually two leaves: raceme subglobose, with very short pedicels: involucre at the base of the flower: perianth-segments narrower, often purplish, nearly equalling the purple capsule: seeds linear, acute at each end, and slightly longer. — Hook. & Arn. Bot. Beechey, 130, t. 29bis. Arctic America.

Var. MAJOR, Hook. Taller, with larger and looser raceme (a half-inch long); the lower pedicels a line long or more, with nodding capsules: seeds a little longer. — On Mackenzie's River.

+ + Tall, with long many-flowered racemes.

3. T. GLABRA, Nutt. Stem 1 to 3 feet high, 2–3-leaved; raceme 2 to 8 inches long: pedicels sometimes in pairs, about equalling the whitish flowers (2 lines long), involucrate near the flower: perianth-segments

oblong-oblanceolate, equalling the oblong-ovate capsule: seeds linear. — *T. glaberrima*, MacBride. N. and S. Carolina; "Arkansas."

* * Stem and inflorescence pubescent: pedicels mostly fascicled: seeds more or less caudate. — § TRIANTHA, Nutt.

4. T. GLUTINOSA, Willd. Glutinous-pubescent: stem slender, ½ to 1½ feet high: leaves 2 or 3 lines broad: raceme short (½ to 2 inches): pedicels (2 lines long in fruit) bearing the scarcely lobed involucre near the flower: perianth not becoming rigid: capsule thin and light-colored, oblong, 2½ lines long, shortly beaked: seeds minute, with close brownish testa, and a contorted tail at each end. — Smith, Trans. Linn. Soc. 12. 246, t. 8, f. 2; Hook. Fl. Bor.-Am. 2. 179, t. 191. *Narthecium*, Michx. Alaska to Oregon, Wyoming and Canada (to New Brunswick), and in the Alleghanies to North Carolina.

5. T. PUBENS, Pers. Pubescence more scabrous: stem 1 to 3 feet high: perianth becoming rigid about the firm dark-colored ovate and long-beaked capsule: seeds larger (¾ line long), with a short white appendage at each end. — Hook. Bot. Mag. t. 3859. *Melanthium racemosum*, Walt. *M. aspericaule*, Poir. *Narthecium pubens*, Michx. *Narthecium* (?) *scabrum*, Raf. New Jersey to Florida and Alabama.

6. T. OCCIDENTALIS. Stem (1 to 2 feet high) and pedicels below the involucres viscid-pubescent: raceme an inch long, and pedicels becoming 3 to 5 lines long: involucre 3-lobed nearly to the middle, often reddish: perianth 2½ or 3 lines long: capsule thin, obovate, 3 or 4 lines long, long-beaked: seeds angular-ovate, with loose white spongy testa, and a slender tail at the outer end nearly as long as the body. — N. California (Mendocino County, n. 1022, Kell. & Harf.) to Washington Territory (Cascade Mountains, Lyall).

48. PLEEA, Michx.

1. P. TENUIFOLIA, Michx. Glabrous: stem a foot or two high: leaves perennial, rather rigid, 1 to 1½ lines wide, the cauline (2 or 3) sheathing: raceme about 6-flowered, the pedicels (an inch long or more) about equalling the conspicuous leafy bracts: perianth-segments 6 lines long, twice longer than the stamens and exceeding the capsule: seeds a line long, shorter than the contorted tail. — Flora, 1. 245, t. 25; Sims, Bot. Mag. t. 1956. North Carolina to Florida.

49. NARTHECIUM, Moehr.

1. N. AMERICANUM, Ker. Stem a foot high or more: leaves a line wide, 7–9-nerved: raceme dense, an inch or two long: perianth-

segments narrowly linear, 2 to 2½ lines long, scarcely exceeding the stamens: filaments covered nearly to the top with dense tangled wool: capsule 5 lines long: seeds ¾ line (or with the tails 3 to 4 lines) long. — Bot. Mag. t. 1505; Baker, Journ. Linn. Soc. 15. 351. *N. ossifragum*, var. *Americanum*, Gray, Manual, 536. New Jersey.

2. N. CALIFORNICUM, Baker, l. c. Leaves usually 7-nerved, 1½ lines broad: raceme open, 3 to 5 inches long: perianth-segments linear-lanceolate, 3 or 4 lines long, a third longer than the stamens: hairs upon the filaments ascending: seeds more numerous (10 to 15 in each cell), a line long (5 lines including the tails). — *N. ossifragum*, var. *occidentale*, Gray, Proc. Amer. Acad. 7. 391. Northern California (Mendocino and Sierra Counties).

50. XEROPHYLLUM, Michx.

1. X. SETIFOLIUM, Michx. Stem 1 to 4 feet high: leaves a line broad or less: raceme becoming 6 inches long or more: perianth-segments oblong-ovate, 3 lines long, exceeding the stamens: styles longer than the ovary: capsule elliptic-oblong, obtuse, 2 lines long: seeds 2 in each cell, not at all appendaged. — *Helonias asphodeloides*, Linn.; Curt. Bot. Mag. t. 748; Lodd. Bot. Cab. t. 394. *X. asphodeloides*, Nutt.; Gray, Manual, 526. New Jersey to Georgia.

2. X. TÈNAX, Nutt. Stem 2 to 5 feet high: leaves about 2 lines broad, often 2 or 3 feet long: raceme becoming a foot or two long, with usually longer pedicels (mostly 1 to 2 inches): perianth-segments oblong, 4 or 5 lines long, scarcely equalling the stamens: styles exceeding the ovary, 2 lines long: capsule broadly ovate, acute, loculicidally 3-valved, nearly 3 lines long: seeds 2 to 4 in each cell, narrowly oblong, 2 lines long, thinner and narrower at the upper end. — *Helonias tenax*, Pursh, Fl. 1. 243, t. 9. *X. setifolium*, Lindl. Bot. Reg. t. 1613. California (Monterey and Plumas Counties) to British Columbia (Lyall).

3. X. DOUGLASII. Pedicels shorter (½ to 1¼ inches long): flowers smaller, the segments (2½ lines long) exceeding the stamens: styles a line long: capsule cordate-ovate, 2 lines long, 6-valved, the abruptly acute cells separating and then dehiscing: seeds shorter and broader. — *X. setifolium*, var., Gray, Proc. Amer. Acad. 8. 405. Collected by Douglas, probably in Oregon, and distributed with his specimens of the last species. Also found by Hall (n. 533) near the Columbia River, and by Hayden in the mountains of Montana on the head-waters of the Yellowstone.

Notes upon the Tribes, etc., — their Affinities and Geographical Distribution.

The entire order of *Liliaceæ* includes about 180 genera and 1900 species, of which 50 genera and 235 species are found in the United States and northward; Mexico adds four genera and 40 species, and South America 26 additional genera and 58 species. The total of American representatives of the order is 80 genera and 333 species. At least 60 of these genera are peculiar to America, while only eight of the species are common to the Old and New World. The West Indies and all of South America to the east of the Andes are almost wholly destitute of species, the order being confined in that continent mainly to the western slope of the Andes, from Peru to Patagonia.

Taking up the tribes in their sequence, the *Allieæ* are represented principally by a single genus, *Allium*, by far the largest and most widely distributed of all the genera of the order. It numbers about 270 species, of which 220 are found in the northern temperate and warm regions of the Old World. No species occur in Australia, and probably none in tropical or Southern Africa. In the New World are about 50 species, mostly in the western United States, a very few Mexican, and a few in South America. Of the two other genera of the tribe, both small, *Nectaroscordium* belongs to the Mediterranean region, and *Nothoscordum* to the warmer portions of both western continents. The subdivisions of *Allium*, as a whole, are not satisfactorily defined, and a careful and thorough revision of this most difficult genus is still greatly needed. Some of the Old World sections are not represented in America, and on the other hand several of our western groups are peculiar. The eastern *A. tricoccum* also is very distinct from all our other species, with apparently some near allies in Europe and Asia.

The *Gilliesieæ*, a very remarkable tribe of Chilian plants, including half a dozen mostly monotypical genera, appear to be most nearly related to the *Allieæ*.

The *Milleæ* are exclusively confined to the western portion of North and South America, only *Androstephium* ranging so far east as Kansas and Texas. The genus *Milla* must be limited to the one species *M. biflora*, all the South American species that have been referred to it probably belonging to *Leucocoryne*, the southern counterpart to the Californian *Brodiæa* and numbering as many species. The genus *Muilla* (the name an inversion of *Allium*) is formed for a plant that has usually been placed with the *Allieæ*, but which has not

the characters of that tribe. In the Old World the only group corresponding to the *Milleæ* is found in the *Agapantheæ* of the Cape of Good Hope.

The genus *Leucocrinum* and the little known Mexican *Weldenia* form an anomalous tribe, which resembles, and not very remotely, the *Massonieæ* of the Cape.

The *Hyacintheæ* and *Scilleæ* (hardly separable as tribes) are limited almost entirely to Europe (with Western Asia) and Africa, two thirds of the 365 species being African. A half-dozen species are found in the East Indies, while in the New World these tribes are represented in the northern continent only by the two species of *Camassia*, and in Chili by a single species, referred to *Ornithogalum*, but probably distinct. As concerns these American species, the one character of a scapose raceme should not separate them from the *Phalangieæ*.

Of the other tribes (or subtribes) having a racemose-paniculate inflorescence and capsular fruit, the *Asphodeleæ* alone (with 40 species) are confined to the Mediterranean region and Western Asia, with a single genus and species in China and Japan. The remainder, the *Phalangieæ*, *Conanthereæ*, *Eriospermeæ*, *Chlorophyteæ* and *Cæsieæ*, belong on the other hand as exclusively to Africa and Australia, but are represented by a considerable number of small genera in the western and warmer portions of North and South America. One genus, *Schœnolirion*, is peculiar to the Southern Atlantic and Gulf States. The Californian species hitherto united with it is here separated under a genus dedicated to Hon. S. Clinton Hastings of San Francisco, whose active interest and generous liberality in behalf of the "Botany of California" deserve at least this recognition. The chiefly African genus *Anthericum*, as extended by Mr. Baker, is doubtless too comprehensive, and the Mexican species referred by him to the subgenus *Hesperanthes* seem to be sufficiently well characterized to form a distinct genus. Several white-flowered species of Mexico and South America are also referred by him to *Anthericum;* the imperfect material at hand does not authorize any other disposal of them, as is moreover the case with the two South American species of *Chlorophyton*, a similar large African genus with a few representatives in Australia and India. The Californian *Odontostomum* is very anomalous in its characters.

Of the baccato-capsular tribes, the *Convallarieæ* (50 species) belong to the whole northern temperate zone, and especially to Asia, only *Smilacina* extending southward into the tropics of America, In Eastern Asia are also found the small allied groups *Liriopeæ* and

Aspidistreæ. The Asparagineous tribes proper (with 180 species) are not represented in America, but are peculiar to Africa (with the Mediterranean region), Australia and Southern Asia, only such outlying genera as *Astelia*, *Luzuriaga* and *Herreria* occurring in South America. The *Nolineæ* may be considered as taking their place in North America.

The *Hemerocallideæ* (36 species), of the same Old World region as the *Asparagineæ*, are represented in America by the one species of *Hesperocallis* in Arizona, which may be included in the tribe notwithstanding the anomalous character of the seeds and root. The *Yucceæ*, of Mexico and the adjacent warm dry region of the United States, in like manner replace the *Aloineæ* and *Sanseviereæ* of Africa and Southern Asia.

The Liliaceous tribes are in general very polymorphous in their characters. The principal one, the *Lilieæ* (of 205 species), which is peculiar to the northern temperate zone and with four of the seven genera common to both continents, may be divided into nearly as many subtribes as genera. *Lloydia* and *Gagea*, chiefly Asiatic, in some respects resemble the *Phalangieæ*, while *Calochortus*, of California and Mexico, and including several well-marked subgenera, is differentiated even more widely in the direction of the *Melanthaceæ*. In the southern hemisphere the only approach to this tribe is found in the *Philesieæ* of two monotypical genera in Chili and Patagonia.

The tribe *Uvularieæ*, of a dozen small genera and about 40 species, is more widely distributed in its types, inasmuch as besides the seven genera of temperate North America and Asia (one species of *Streptopus* ranging westward from America to Central Europe), Africa and S. Asia have a representative in the genus *Gloriosa*, Australia in *Burchardia* and its allies, and Chili in *Callixene*. The division of *Uvularia* itself, which seems to be required, affords an opportunity to honor the memory of the lamented botanist, Mr. William Oakes, whose persistent zeal in investigating the flora of the fields and mountains of his native New England makes appropriate the union of his name with one of the plants which he himself knew so well.

The *Trillieæ* are a small tribe exclusively northern, the principal genus *Trillium* American (with one species entering E. Asia) but represented in Asia by two nearly allied genera, *Paris* and *Trillidium*, of which the first also occurs in Europe. Less near are the two other genera *Medeola* and *Scoliopus*, which occupy respectively the eastern and western coasts of North America. The tribe has no counterpart in the southern hemisphere.

The *Melanthaceæ* form the least of the three divisions of the order, numbering 28 genera and only 112 species. The *Colchiceæ* belong exclusively to Europe and the Mediterranean region. The *Veratreæ* are almost as exclusively North American, a few species occurring in Eastern Asia and *Veratrum* extending into Europe. It is the only tribe that in North America enters Mexico, and the only one that finds representation in the southern hemisphere in the allied *Anguillarieæ* of Africa and Australia. The *Helonieæ* have two monotypical genera in the Atlantic States, and three others (including *Metanarthecium*) in Japan. The *Tofieldieæ*, occupying the northern temperate zone, seem to have a solitary representative (a species of *Tofieldia*) in the mountains of Peru, while *Hewardia* of Australia is in some respects analogous to *Pleea* of the Southern Atlantic States.

In general and in conclusion, this hasty and imperfect sketch of the more prominent facts in respect to the distribution of the order, while showing the evident connection of the northern floras of the continents, also indicates a certain, though more distant, relationship (however it may be accounted for) between the flora of Pacific America and that of South Africa and of Australia.

II. *Descriptions of some new Species of North American Plants.*

THALICTRUM POLYCARPUM. Rather stout, 2 or 3 feet high or more, glabrous throughout: leaves with short petioles or the upper sessile; leaflets variable, 3 to 12 lines long, the lobes acutish to acuminate: panicle narrow, often small; the staminate usually crowded, with flowers on short pedicels: anthers linear, acute, on very slender filaments: styles scarcely attenuate upward: fruit usually in dense heads, compressed, broadly oblong-obovate or obovate, abruptly acute, subreticulately 3–5-nerved, 2½ or 3 lines long: seed linear, terete, nearly 2 lines long. — *T. Fendleri*, var. (?) *polycarpum*, Torr. in Pacif. R. Rep. 4. 61, in part. *T. Fendleri*, Brew. & Wats. Bot. Calif. 1. 4, mainly. Pacific Coast Ranges from Monterey (or Los Angeles ?) to Oregon (Washington County, J. Howell); also in the Sierra Nevada. — T. OCCIDENTALE, Gray, is a similar species, with more slender open panicles, the staminate very diffuse with slender elongated pedicels; style attenuate; fruit usually few (1 to 6) in each head, narrowly oblong (3 to 4 lines long) and attenuate at each end; seed nearly 3 lines long. It ranges from British Columbia to W. Montana and N. E. California (Plumas County, Mrs. Austin).

The leaflets are somewhat larger, rarely with a slight minute puberulence beneath. — T. Fendleri, Gray, of the Rocky Mountains (Colorado and Utah to New Mexico), is a rather low slender species, glabrous or somewhat pubescent, with usually small leaflets (2 to 9 lines long) and an open spreading panicle; anthers setosely acuminate; fruit slightly glandular-puberulent, oblong to ovate, acuminate, 2 or 3 lines long; seed broader and somewhat flattened, 1½ lines long. *T. Wrightii* appears to be a form with fruit smaller than usual.

Ranunculus ambigens. In wet places, glabrous, the ascending stems stout and elongated, often rooting at the lower joints: leaves oblong- to linear-lanceolate, 2 to 5 inches long, acute, sparingly denticulate, petiolate; petiole margined, clasping: petals (2 lines long) but little exceeding the sepals: carpels in small ovate heads, turgid, rarely a line long, with a long straight narrowly subulate beak. — *R. alismæfolius*, Benth. Pl. Hartw. 295, as to the eastern plant, and Gray, Manual, 41. From Maine to Illinois. — R. alismæfolius, Geyer, to which this has been referred, has an erect stem (a foot high or more, the alpine form often dwarf) from a fleshy-fibrous root, glabrous excepting the hairy basal sheaths; leaves entire, the radical on elongated petioles, the few cauline sessile or nearly so; petals larger (2 to 6 lines long); fruiting heads usually larger, the more flattened carpels over a line long, with a short narrow beak. It is found in the mountains from Colorado and Wyoming to California and Oregon. The var. *montanus* of King's Rep. is the typical subalpine form as found by Geyer.

Dentaria Californica. Stem simple or branched, about six inches high: leaves thick, 2 to 4 on the upper part of the stem, on short petioles, ovate to round-reniform, cordate or sometimes cuneate at base, obscurely sinuate-dentate or coarsely and sharply or laciniately toothed, very rarely 3-lobed: petals rose-colored, 4 to 6 lines long, more than twice longer than the purplish sepals: pedicels spreading (3 to 9 lines long): pod 12 to 18 lines long by a line wide, attenuate into a very slender style (2 lines long or more), — or in Var. pachystigma, the pod much stouter and broader, with a very short stout style. — Mountains of Plumas County, California; J. G. Lemmon, Mrs. R. M. Austin, and Mrs. M. E. P. Ames. The root is a small deep-seated tuber. Referred to in the Botany of California under *Cardamine paucisecta*.

Draba montana. Annual, hoary throughout with a rather dense villous pubescence: stem stout, simple or branched, leafy, 3 to 10 inches high: leaves rosulate at base, lanceolate, obtusish, entire or

sparingly toothed, 3 to 8 lines long: raceme many-flowered, elongated: flowers yellow, becoming whitish, small: pods erect on the short divaricate pedicels, elliptic-oblong, obtuse, pubescent, 4 lines long by a line broad: style none. — Rocky Mountains of Colorado; South Park, Wolf & Rothrock (n. 637); near Empire, E. L. Greene; also collected by Hall & Harbour. — D. STENOLOBA, Ledeb., is much more slender and less pubescent (nearly glabrous above), with narrower leaves, looser racemes, and narrower glabrous pods acutish at each end. — D. NEMOROSA, Linn., to which both have usually been referred and which is also frequent in the Rocky Mountains, is of lax spreading habit, with the ovate-oblong to lanceolate leaves rarely rosulate at base, pale yellow flowers, and the usually slightly pubescent pods (2 to 4 lines long) much shorter than the slender pedicels.

THELYPODIUM AMBIGUUM. A stout erect glabrous and glaucous branching biennial, 3 to 5 feet high: leaves sessile, broadly auricled, the lower oblanceolate, coarsely serrate, 6 to 8 inches long, the upper ovate to lanceolate, acute, mostly entire: flowers reddish purple, on spreading pedicels (3 or 4 lines long) in an open raceme; petals with an ovate-oblong blade and rather narrow claw, nearly twice longer than the oblong obtuse purplish sepals (2½ lines long): pod elongated, narrow (3 inches long by less than a line broad), terete and subtorulose, recurved-spreading; stipe slender, nearly 2 lines long: stigma sessile, capitate. — Northern Arizona, Dr. Newberry on Lieut. Ives's Expedition (*Streptanthus sagittatus* of Ives's Report), and Dr. E. Palmer in 1877 (n. 27). Also n. 109, Watson, from Regan's Valley, N. Nevada, is apparently the same.

VIOLA CUNEATA. Glabrous: stem a span long, leafy, ascending from a short rootstock: leaves rhombic-ovate, acute, attenuate at base into a slender petiole, crenately toothed above: petals deep purple, more or less bordered or blotched with white, beardless, 4 lines long; spur very short, yellowish: capsule glabrous. — Humboldt County, California, on a high open ridge south of Trinity River; V. Rattan, June, 1878. Allied to *V. ocellata* and *V. Hallii.*

SILENE SARGENTII. Low and alpine (6 inches high), puberulent, cespitose and many-stemmed, with the habit of dwarf forms of *S. Douglasii*, to which it is allied: leaves linear, slightly oblanceolate, 1 to 2 inches long: flowers 3 to 6: calyx 6 or 7 lines long, cylindrical, with short teeth: petals about 10 lines long, the obovate bifid blade with a small tooth on each side; auricles broad, laciniately toothed; appendages large and broad, toothed: styles long-exserted: capsule narrowly cylindrical, long-stipitate: seeds minutely tuberculate on the

back. — On Table Mountain of the Monitor Range, N. Nevada, at 10,000 feet altitude; Prof. C. S. Sargent, 1878.

SILENE GRAYII. Low and alpine (3 to 6 inches high), cespitose, grayish-puberulent: leaves oblanceolate, 6 to 8 lines long: flowers 2 or 3: calyx broadly cylindric, with deep-rounded teeth, 5 or 6 lines long: petals rose-color, 7 or 8 lines long, the broad blade bifid to the middle with a prominent tooth on each side; claw broad with narrow entire auricles; appendages broad, entire or nearly so: capsule short, nearly sessile. — Mount Shasta, near snow; W. H. Brewer, 1862 (n. 1373); Hooker & Gray, 1877; A. S. Packard, Jr., 1877.

PSORALEA CASTOREA. Stems very short from a tuberous root, decumbent; the whole plant covered with white straight closely appressed rather rigid hairs: leaves digitately 3–5-foliolate, on stout petioles 2 or 3 inches long; leaflets cuneate-obovate, rounded or acutish at the apex, less pubescent above, an inch long; stipules ovate-lanceolate, scarious, persistent: peduncles shorter than the petioles: spike rather dense, about an inch long, with conspicuous foliaceous bracts as long as the calyx (4 or 5 lines), spatulate and abruptly acute: calyx-lobes linear, acuminate, nearly equalling the blue petals: pod thin, lanceolate, 5 lines long: seed compressed, nearly 2 lines long. — Near Beaver City, S. Utah, on sandy ridges; Dr. E. Palmer (n. 96, 1877). Belonging with the next to the *P. esculenta* group, and distinctly marked by the large foliaceous bracts.

PSORALEA MEPHITICA. A similar species, softly pubescent throughout and villous with more or less spreading hairs: leaflets 4 or 5, obtuse or retuse: stipules broadly ovate: peduncles about equalling the petioles: flowers on very short slender pedicels in a close raceme an inch long: bracts mostly scarious, ovate, acuminate or acute, rather shorter than the calyx (4 to 6 lines): calyx-lobes linear to oblong-lanceolate, lax, equalling the blue petals: pod small, somewhat chartaceous, villous above. — Same locality; Dr. E. Palmer (n. 97, 1877), who describes it as having the odor of the skunk.

VICIA REVERCHONI. Annual, pubescent with spreading hairs, the decumbent stem angled and narrowly winged, a foot high: leaflets 3 or 4 pairs on a broad rhachis, cuneate-oblong or the lower obovate, rounded or truncate and mucronate at the summit, 4 to 7 lines long: flowers solitary, small (3 lines long), light blue, the narrow acuminate calyx-teeth about equalling the tube: pod pubescent, shortly pedicellate on a peduncle an inch long or more, 10 to 15 lines long by 2 lines broad, 10–15-seeded. — On sandy prairies near Dallas, Texas; J. Reverchon, April, 1877.

VICIA FLORIDANA. Glabrous, with very slender elongated stems: leaflets 2 or 3 pairs, oblong-elliptic, cuneate at base, rounded and mucronate above, 5 to 10 lines long; stipules very small and narrow: peduncle 1–6- (usually 1–2-) flowered, ½ to 2 inches long: flowers small and pale (3 lines long), on very short pedicels; calyx-teeth broad, much shorter than the campanulate tube: pod glabrous, 1–2-seeded, shortly stipitate, acuminate, ½ inch long by 2 lines broad or more. — Florida, Buckley; upper St. John's River, W. M. Canby; rich woods near Jacksonville, and shell-islands at mouth of St. John's River, A. H. Curtiss. Apparently *V. acutifolia* var. β, Torr. & Gray, Flora, 1. 272; growing in large patches, and probably a perennial.

BOLANDRA OREGANA. Resembling B. CALIFORNICA in habit, but stouter (15 to 20 inches high) and more pubescent and glandular especially above: leaves laciniately toothed and lobed: flowers larger, the calyx-tube (about 3 lines long) equalling the teeth and a little shorter than the deep purple petals: pedicels reflexed in fruit: beaks of the ovary and capsule more attenuate: seeds dull, dark brown, a third of a line long. — On wet rocky banks of the Willamette River, near Oregon City, Oregon; J. Howell, June, 1877.

SULLIVANTIA OREGANA. Stoloniferous, slender, with the habit of *S. Ohioensis*, glandular above: leaves round-cordate, acutely and rather laciniately toothed, an inch in diameter or less: petals obtuse, oblong-obovate, a half longer than the sepals (1½ lines long), somewhat crenate: seeds dark-brown and shining, narrowly winged, two thirds of a line long. — Discovered by the same collector in the same locality, and also on the rocky banks of the Columbia River. — S. OHIOENSIS has oblanceolate acutish petals, and smaller light-brown seeds with a thinner more distinct wing. It appears not to be stoloniferous.

COTYLEDON PALMERI. Caulescent: leaves not at all mealy or glaucous, reddish, lanceolate and acuminate (narrowing from the base to a very sharp point), 2 inches long by 8 or 9 lines wide at base, the margin obtuse: stem a span long, red, with scattered broadly triangular-ovate leaves, the lower more acuminate: inflorescence of a few simple spreading secund racemes, somewhat glaucous: pedicels 3 to 6 lines long: calyx rather broad, with triangular-ovate sepals 2 lines long: petals pale lemon-yellow, 5 or 6 lines long, scarcely carinate, the midvein not glaucous: carpels 4 lines long, at length somewhat spreading and with divergent styles. — San Simeon Bay, California; Dr. E. Palmer, 1877.

COTYLEDON LINGULA. Much like the last: leaves oblong, acute, 2 or 3 inches long by an inch broad: stems 1½ to 2 feet long, the branches of the cyme less spreading and short: pedicels very short (a line or less): sepals narrower and longer: carpels 3 lines long, somewhat spreading, with straight styles. — From the same region and collector. Described from living specimens, as also the last.

ŒNOTHERA AMBIGUA. Annual, with a short leafy stem and sending out naked horizontal branches from the base, the epidermis white and smooth: leaves oblanceolate, sinuately toothed or nearly entire, 3 or 4 inches long, with short appressed pubescence, as also the inflorescence: flowers nodding in the bud, white or cream-color becoming purplish; tips of the calyx free; petals 9 to 15 lines long: capsules linear, thickest toward the base, spreading or reflexed, an inch long or more: seeds linear, smooth, a line long. — Near St. George, S. Utah; Dr. E. Palmer (n. 162, 1877); also Dr. Parry in 1874, distributed as *Œ. albicaulis*, var. *decumbens*. It is closely allied to that species, but Dr. Palmer's specimens show it to be clearly distinct in habit, foliage and duration; the seed is also longer and narrower.

LIGUSTICUM TENUIFOLIUM. Stem slender, 12 to 18 inches high, naked above the base or with a single sessile leaf, and bearing a single naked umbel with rarely a lateral sterile one: leaves small (2 or 3 inches long), ternate and pinnately decompound, finely dissected with laciniately divided leaflets, the ultimate segments linear, a line or two long: rays few (7 to 11), an inch long or less: involucels of 1 or 2 narrowly linear bracts: fruit (scarcely mature) oblong, 2 lines long, narrowly ribbed, with narrow disk and conical styliphore: seed concavo-convex. — Mountains of Colorado; Hall & Harbour (n. 216, in part); Wolf & Rothrock, n. 721. Leaves much more finely divided even than in *L. filicinum*, and fruit very different.

PEUCEDANUM GEYERI. Low and acaulescent or nearly so, glabrous; root moniliform with 2 or 3 small globose tubers (a half-inch thick or less): leaves ternate-quinate, the leaflets linear, 4 to 9 lines long: flowers white, in small unequal-rayed umbels: involucel of several linear acuminate bracts: mature fruit unknown. — Collected by Geyer (n. 458), and on the Clear Water, Idaho, by Rev. Mr. Spalding, who gives the Indian name "Lakaptat." — P. FARINOSUM, Geyer, is a similar dwarf white-flowered species, having a solitary small globose tuber with frequent clusters of fine rootlets over its surface: fruit oblong-elliptic, 2 or 3 lines long, with numerous dorsal vittæ (3 or 4 in each interval) and 4 on the commissure. It ranges

from Wasington Territory to Idaho and N. California (Sierra County, J. G. Lemmon). There still remains some uncertainty respecting the other tuberous-rooted species which yield the "Biscuit-root" of the Indian tribes of Oregon. There seem to be two, both nearly acaulescent, with large somewhat fusiform tubers, linear leaflets, and white flowers, — one described by Spalding as "the famous Biscuit-root or 'Kamshit' (when dried, 'Kanash'), dug in large quantities in May," and the other somewhat taller, distinguished by him as "a large kind of Kamshit, the root not as good" as the other. Ripe fruit is unknown; the immature ovary indicates an oblong fruit with strong dorsal ribs.

ASARUM LEMMONI. Slender, somewhat pubescent, with elongated rootstocks: leaves cordate, rounded at the summit, thin and not mottled, glabrous above or nearly so: flowers rather small and mostly glabrous, with the short calyx-lobes (4 to 6 lines long) obtuse or only acute: connective but slightly produced beyond the anther: seeds narrowly ovate. — In the Sierra Nevada; Plumas and Sierra Counties, Mrs. R. M. Austin and J. G. Lemmon. Resembling *A. caudatum* of the Coast Ranges; distinguished especially by the more rounded leaves and short calyx-lobes.

ABRONIA NANA. Perennial, dwarf and cespitose, with a thick branching caudex: stems very short and leafy: leaves ovate (a half-inch long or less), rough-puberulent, with slender glandular-pubescent petioles an inch long: peduncles 2 or 3 inches long, glandular-pubescent: involucre of 4 or 5 ovate-oblong scarious bracts, reddish at base, 4 or 5 lines long: flowers greenish, 6 or 7 lines long, the reddish limb 4 lines broad: ovary turbinate, with 5 hollow wings: fruit unknown. — Near Beaver City, S. Utah, in dry ravines among junipers; Dr. E. Palmer (n. 404½, 1877).

POLYGONUM (DURAVIA) BIDWELLIÆ. Low (2 to 4 inches high): leaves and bracts cuspidate, brownish: spikes short, dense: stipules conspicuous, white, scarious and chaff-like, often exceeding the bracts (2 lines long), 2-lobed, the lobes entire or slightly lacerate at the summit: flowers pale rose-color, nearly a line long: akene narrowly ovate, included; the styles widely divergent. — Near Chico, California; Mrs. John Bidwell, May, 1878. With the following species allied to *P. Californicum* and confirming the section *Duravia*, which is to be distinguished from *Avicularia* chiefly by the linear 3-nerved leaves and bracts, not jointed at the base, the solitary sessile spicate flowers, and the persistent styles. The original characters of the section as respects the fruit were drawn from immature specimens and are erroneous, the akene not differing essentially from that of

Avicularia. All the species are low slender erect and branching annuals. — P. CALIFORNICUM, Meisn., is somewhat taller, with longer narrower and looser spikes, short sheathing deeply lacerate stipules, shorter bracts scarcely equalling the slightly larger flowers, and a longer akene with but slightly divergent styles.

POLYGONUM (DURAVIA) GREENEI. Resembling *P. Californicum*, with denser spikes, the bracts and wholly fimbriate stipules 2 lines long: styles very short, somewhat spreading. — Plains of Shasta, Rev. E. L. Greene, 1876; near Chico, Mrs. J. Bidwell, July, 1878.

POLYGONUM (PERSICARIA) MUHLENBERGII. Perennial, in muddy or dry places, often 2 or 3 feet high, scabrous with short appressed or glandular hairs, especially upon the leaves and upper stem: leaves thin, rather broadly lanceolate, long-acuminate, usually rounded or cordate at base, 4 to 7 inches long, on short stout petioles (½ to 1 inch long) from near the base of the naked sheath: flowers and fruit nearly as in *P. amphibium*, but spikes more elongated (1 to 3 inches long), often in pairs. — New England to Texas and westward to Washington Territory and N. California. *P. amphibium*, var. (?) *Muhlenbergii*, Meisn. in DC. Prodr. 14, 116, and including most of the var. *terrestre* of American botanists. Our subterrestrial form of *P. amphibium* seems rarely if ever to correspond to the var. *terrestre* of Europe.

ERIOGONUM (EUERIOGONUM § FOLIOSA) PUBERULUM. A low annual, dichotomously branching from near the base, appressed silky-puberulent throughout: leaves all radical, obovate, 3 or 4 lines broad: bracts foliaceous, mostly ternate, narrowly oblong, 2 lines long or less: involucres sessile in the forks, very small, 4-parted: flowers few, glabrous, rose-colored, about ⅔ of a line long: sepals oblong. — On Red Creek, S. Utah; Dr. E. Palmer (n. 429, 1877).

ERIOGONUM (GANYSMA § PEDUNCULATA) HOOKERI. Glabrous, a foot high or more; stem slender, not branching near the base as do the rest of the group: leaves densely floccose-tomentose both sides, orbicular: involucres campanulate, sessile or nearly so, reflexed and secund upon the branches: flowers pale yellow, the outer sepals subreniform-cordate, a line long; the inner oblong-ovate, half as long: akene abruptly beaked, ½ line long. — Wahsatch Mountains, American Fork Cañon (n. 1033 Watson, at least in part); W. Nevada, Hooker & Gray, 1877. Referred in King's Rep. 5. 306 to *E. deflexum*, which branches from the base, has more turbinate involucres, smaller flowers with narrower rose-colored sepals, and a more attenuate akene.

ERIOGONUM INSIGNE. Of the same group: becoming very stout and 2 or 3 feet high, glabrous excepting the reniform-cordate densely

white-tomentose radical leaves (an inch or two in diameter): involucres in the forks and secund on the short branches, large for the section (a line long or more), turbinate and somewhat angled, erect or nearly so on pedicels 1 to 3 lines long: flowers glabrous, rose-colored, becoming nearly a line long, the sepals oblong-ovate, subcordate at base: akene attenuate, $\frac{2}{3}$ of a line long. — Near Red Creek, S. Utah; Dr. E. Palmer (n. 431, 1877).

ERIOGONUM (OREGONIUM § CORYMBOSA) SULCATUM. A woody very diffusely and intricately branched floccose-tomentose perennial, nearly glabrous above, the branches very strongly angled and sulcate: leaves narrowly oblanceolate, thin and lax, an inch long or less, silky-tomentose, less so above: bracts very small: involucres minute ($\frac{1}{2}$ to $\frac{2}{3}$ of a line long), sessile, glabrous. — Near St. George, S. Utah; Dr. E. Palmer (n. 432, 1877). Allied to *E. microthecum*; very distinctly marked by its angular branches.

HOLLISTERIA; new genus of *Eriogoneæ*. Involucre unilateral, of 3 equal slightly united linear herbaceous (not cuspidate) bracts, solitary and sessile in the axils, 2-flowered. Perianth turbinate, membranous, 6-cleft to the middle, the slender segments not rigid nor awned. Stamens 9, on the throat, included. Akene glabrous, triangular above. Embryo curved, the slender radicle accumbent to the orbicular cotyledons. — A small fragile leafy annual, diffusely branched from the base, white-woolly throughout; leaves apparently all alternate and foliaceous, but these each with a very small stipule-like pair at base, all cuspidate; flowers on short unequal pedicels, with a minute scarious bractlet at base. — A single species; the genus dedicated to Col. W. H. Hollister, of Santa Barbara, upon whose ranch it was found, and through whose aid and encouragement Mr. J. G. Lemmon made the collection in which it was detected.

HOLLISTERIA LANATA. Decumbent or prostrate, covered with a loose white woolly tomentum, which is less dense on the lower leaves: leaves oblanceolate, attenuate at base, the lower 1 to 3 inches long, the upper much shorter and narrowly ovate, aculeate-tipped; the stipule-like pair linear-subulate (1 to 3 lines long): perianth very woolly externally, a line long, the linear-lanceolate segments green with a scarious margin, the inner slightly shorter and broader: filaments filiform: styles slender: akene black, ovate with a stout triangular beak. — Near San Luis Obispo.

SUÆDA INTERMEDIA. Perennial, the straight erect slender herbaceous stems from a short woody base, 9 to 18 inches high, glabrous or sometimes puberulent; branchlets also slender, ascending: leaves

very narrowly linear with a contracted base, acute, 6 to 10 lines long, much shorter on the branches: fertile flowers very small, often solitary, the deeply cleft calyx unappendaged: seed very small (⅓ of a line broad), horizontal, not at all tuberculate under the microscope. — Utah and Arizona; Dr. C. C. Parry (n. 218, S. Utah, 1874, and n. 84, Central Utah, 1875); L. F. Ward, on Powell's Survey (n. 152 and 718, 1875); also Hooker & Gray, 1878. Somewhat resembling *S. suffrutescens*, which is more shrubby and pubescent, with lax and flexuous stems, stouter and obtuser leaves, calyx less deeply lobed, and the usually vertical seed obscurely tuberculate.

Celtis brevipes. A small tree (becoming 20 feet high and 18 inches in diameter), sparingly pubescent: leaves small (1 to 1½ inches long), entire, oblong-ovate, acuminate, rounded or cuneate at base, rather thin, finely but conspicuously reticulated, roughish above: fruit nearly 3 lines long, on slender pedicels about equalling the very slender petioles (2 lines long). — Near Camp Grant, Arizona; Dr. J. T. Rothrock (n. 367), on Lieut. Wheeler's Survey, 1874.

Croton (Drepadenium) tenuis. Perennial, woody at base, with slender decumbent stems a foot or two high: leaves narrowly oblong, a half to one inch long, with short petioles (1 to 4 lines): staminate flowers small and in small racemes: capsule 2 lines long: caruncle of the seed prominent, with a broad appressed lobed base. — S. California; Potrero, S. Diego County, D. Cleveland; Soda Lake, near Fort Mohave, Cooper. — C. Californicus, Muell., differs in its less slender habit and broader leaves with longer petioles, and especially in its larger flowers and much larger capsules and seeds, the latter with a small appressed caruncle. It differs also both in habit and fruit from the allied *C. Neo-Mexicanus* of S. Utah and New Mexico, and the Mexican *C. gracilis*.

Stillingia linearifolia. Perennial, branching from a woody base, the herbaceous slender terete ascending stems a foot high or more: leaves linear, entire or rarely slightly glandular-toothed, acute, sessile, 6 to 12 lines long: spikes terminal, very slender and open, 1 to 1½ inches long, with very small ovate acute 1-flowered bracts, minutely glandular on each side: staminate flowers with turbinate calyx, diandrous: pistillate flowers 2 to 7, scattered, without calyx: capsule 1½ lines long; horns of the gynophore rather thin, and central column often persistent: seed broadly ovate, acute, a line long, smooth, without caruncle. — S. California; near Boundary Monument, San Diego, Dr. E. Palmer (n. 449, 1875); San Bernardino, Parry & Lemmon (n. 376, 1876). Referable, with the following

species, to Mueller's *Gymnostillingia*, which may be considered a section or subgenus, characterized by solitary staminate flowers, the pistillate ones naked, and the seed without caruncle.

STILLINGIA PAUCIDENTATA. Differing from the last in its stout angled stems branching above; leaves acuminate, an inch or two long, with 2 or 3 setaceous teeth on each side near the base; spikes stouter and denser, the pistillate flowers more crowded; capsule larger, with more prominent gynophore, and the larger seed oblong-ovate, slightly carunculate. — Colorado Valley, near mouth of Williams River; Dr. E. Palmer (n. 517, 1876).

STILLINGIA TORREYANA. A low glabrous annual (?), with angled leafy stems: leaves oblong-obovate, cuneate at base, rounded above, obscurely veined, acutely and sometimes doubly toothed, 6 to 10 lines long, with minute fimbriate caducous stipules: spikes terminal, sessile, short and slender: bracts very small, ovate, acute, 1-flowered, with nearly sessile disk-like glands: staminate calyx campanulate, diandrous, the pistillate of 3 triangular sepals: capsule over 2 lines broad, with stout gynophore: seeds oblong-ovoid, 1¼ lines long, smooth, with conspicuous prominent caruncle. — Valley of the Rio Grande, at Eagle Pass; Dr. Bigelow, 1852. *Sapium annuum*, var. *dentatum*, Torr. in Bot. Mex. Bound. 201, and referred doubtfully by Mueller to *Sebastiana Treculiana*. The latter, from the same region and much resembling the present species, is distinct though doubtless a congener. It is described as a perennial, 1 to 1½ feet high, with a woody base. Its leaves are oblanceolate, acutish, 10 to 15 lines long; the capsule somewhat smaller, with a short stout-horned gynophore and large persistent central column; the seed smaller, subglobose, irregularly tuberculate, and with much smaller caruncle.

CALLITRICHE SEPULTA. Terrestrial, prostrate and rooting, with numerous narrowly linear leaves 2 or 3 lines long: bracts none: fruit broader than long, emarginate at each end, the thick carpels with acute divergent margins, on stout pedicels a line or two long, soon deflexed and buried in the soil: styles elongated, reflexed, soon deciduous. — Oregon; E. Hall (n. 459). Allied to *C. deflexa*, A. Braun (*C. Austini*, Engelm.), and to *C. Nuttallii*, Torr., of which the latter has the same habit of burying its fruit.

EPHEDRA NEVADENSIS. An erect shrub, 2 feet high or more, with opposite erect or somewhat diffusely spreading branches; bark splitting and becoming white and shreddy or fibrous: scales opposite, sheathing, with short acute lobes or somewhat elongated foliaceous tips, usually 1 to 3 lines long, at length mostly deciduous: staminate

aments sessile or nearly so, of 4 to 6 pairs of connate bracts: filaments long-exserted, united throughout or the anthers (4 to 8) shortly stipitate: fertile flowers upon a scaly-bracted (rarely naked) peduncle 1 to 6 lines long; bracts 4 or 5 pairs, round-ovate, connate: fruit solitary or in pairs, 3 or rarely 4 lines long, exserted, acutish, smooth; micropyle a line long. — *E. antisyphilitica*, Watson, Bot. King. Exp. 328, t. 39. Throughout the interior from N. Nevada to the Colorado Desert (Fort Mohave, Cooper), Northern Mexico (Gregg), and the Rio Grande. The New Mexican form has more usually very short peduncles and solitary fruit. Californian specimens collected at Fort Tejon (n. 112, Xantus) and in the Santa Inez Mountains (n. 347, Brewer), without flowers or fruit, are peculiar in having persistent scales and may possibly prove distinct.

EPHEDRA[1] TORREYANA. Erect, 1 to 3 feet high or more, the branches often somewhat flexuous, not spinose, usually ternate: scales short (a line or two long), sheathing, ternate, with broad and acutish or rarely narrow lobes, subpersistent, not becoming shreddy: staminate

---

[1] The North American species of this genus may be defined as follows: —

* Scales 2-lobed and the branches (not spinose) opposite: bracts in pairs and evidently connate, scarcely at all scarious: fruit solitary or in pairs, smooth.

1. E. ANTISYPHILITICA, C. A. Meyer. Stems mostly lax and slender, declinate and nearly prostrate or supported on shrubs or trees to a height of 8 or 10 feet; bark not shreddy nor fibrous: scales distinct, subpersistent, very short and triangular-ovate, or when young setaceously tipped and slightly sheathing (sometimes 2 lines long): aments on short bracteate peduncles: filaments distinct above the perianth: fertile flowers with 3 or 4 pairs of bracts: fruit 2½ or 3 lines long: otherwise as the next, but micropyle slightly shorter. — W. Texas and New Mexico (n. 320, 1590, Berlandier; n. 673, 1881, Wright; n. 225, 273, 428, Lindheimer), to Northern Mexico (n. 855, Parry & Palmer, 1878).

2. E. NEVADENSIS, Watson. See above.

* * Scales ternate and branches mostly in threes: bracts ternate, distinct or slightly connate, those of the fertile flowers more or less conspicuously scarious and unguiculate: fruit solitary or in threes.

3. E. TRIFURCA, Torr. Erect, much branched, 2 to 6 feet high, the straight rigid branches spinosely tipped: scales conspicuous, sheathing, 3 to 6 lines long, sharply acuminate, persistent, becoming whitish and shreddy: staminate aments on a very short peduncle, of 5 whorls of ovate bracts about equalling the cuneate-oblong perianths: anthers (4 or 5) stipitate: fertile flowers nearly sessile, 5 or 6 lines long, of numerous whorls (8 to 10) of very thin and scarious entire round-cordate unguiculate bracts: fruit solitary, 6 lines long, 4-sided, attenuate upward, smooth: micropyle 2½ lines long. — Arizona and New Mexico; Mohave Agency, Dr. E. Palmer (n. 523½, 1876); near El Paso, Dr. Bigelow; near Fronteras, Wright (n. 1884).

4. E. TORREYANA, Watson; and 5. E. CALIFORNICA, Watson. See above.

aments nearly sessile, of 6 to 8 whorls of broad bracts; perianth round-ovate, slightly exserted; anthers 5 to 8, stipitate: fertile flowers 3 to 5 lines long, on a very short peduncle, of 5 or 6 whorls of thin broadly dilated unguiculate more or less crenulate bracts: fruit solitary or in threes, oblong-lanceolate, scabrous, 4 lines long or less: micropyle a line or two long. — New Mexico to S. Utah; Fronteras (n. 1883, Wright); El Paso (Bigelow); Santa Fé (n. 80, Rothrock); S. Utah (n. 250, Parry, 1874).

Ephedra Californica. Stems ascending or decumbent, the ternate branches not spinose: scales in threes, sheathing but soon splitting to the base and recurved, 1½ to 3 lines long, the oblong acutish lobes long-persistent, becoming dark-colored: staminate aments globose, sessile, of 4 whorls of nearly distinct bracts; perianth broad, included; anthers 4 or 5, sessile: fertile flowers sessile, of 4 or 5 whorls of rather rigid scarious reniform-orbicular sessile bracts, the upper with a broad and very short claw: fruit solitary, ovate, somewhat 4-angled, acutish, smooth, 3 to 3½ lines long. — San Diego County, California; promontory near San Diego and Jamul Valley, Dr. E. Palmer (n. 364 and 365, 1875).

Cupressus Guadalupensis. A widely spreading tree, becoming 40 feet high or more, and 2 to 5 feet in diameter, with grayish-brown bark cleaving off in thin plates and leaving the thin inner bark with a smooth claret-red surface: branches drooping and branchlets very slender: foliage glaucous-green, the acute or acutish leaves very obscurely glandular on the back: cones globose, an inch or more in diameter, of 6 or 8 very thick and strongly bossed scales: seeds numerous, large (3 lines long or more). — On Guadalupe Island, off the coast of Lower California; distributed as *C. macrocarpa* in Dr. E. Palmer's collection from that island. In cultivation about San Francisco, and likely to prove very valuable for ornamental purposes.

Zephyranthes Treatiæ. Bulb small (a half-inch in diameter): leaves thick, semi-terete with rounded margins, very narrow (rarely 1½ lines wide), deep green and not shining: scape 4 to 12 inches high: spathe in the fresh flower closely sheathing the ovary and stout peduncle: flower 3 inches long, white becoming pinkish; segments obtusish: anthers short, 1½ to 3 lines long: capsule broader than long (5 or 6 lines), on a peduncle 3 to 9 lines long. — In wet or moist places, Florida; near Green Cove Springs, Mrs. Mary Treat; on the St. John's River, near Jacksonville, Dr. E. Palmer and A. H. Curtiss. Distributed as *Amaryllis Atamasco* in the collections of the latter. It

flowers in April and May. — Z. Atamasco, Herb., growing in the same region and northward, but in drier localities and blooming several weeks earlier, has thin channelled leaves with acute margins, bright green and shining, 1½ to 2½ lines wide, a loose spathe, the flower with a more slender tube and peduncle, rather broader and more acute segments, and anthers 3 or 4 lines long. The most obvious distinction is found in the foliage.

Hymenocallis Palmeri. Bulb small (4 or 5 lines thick), narrowly oblong, with thick roots: leaves with short sheaths, very narrow, a foot long by 3 lines wide or less: scape slender, 8 or 10 inches high, 1-flowered: spathe-segments 3, narrowly linear: perianth-tube scarcely dilated above, about equalling the narrow (a line wide) segments, which are 3½ or 4 inches long: crown tubular-funnelform, 15 lines long, the border acuminately lobed between the stamens: filaments a third shorter than the perianth; anthers greenish: ovary oblong-ovate, 9 lines long. — Biscayan Bay, Florida, Dr. E. Palmer (n. 554, 1874).

Hymenocallis humilis. Bulb twice larger, upon a thick rootstock: leaves with broad sheathing bases, 4 to 6 inches long by 2 lines broad: scape slender, scarcely equalling the leaves, 1-flowered: spathe-segments 3, greenish, narrowly linear: flowers greenish; tube scarcely dilated above, 15 lines long, shorter than the narrow segments (2 inches long); crown broadly funnelform, 8 lines long, truncate between the stamens: filaments a third shorter than the perianth and style: anthers greenish: ovary narrowly oblong, 5 lines long, becoming an inch long in fruit. — Indian River, Florida; Dr. E. Palmer (n. 555, 1874). Though our species of this genus cannot be said to be well known, yet it seems to be safe to propose the above as new species, differing so markedly as they do from any previously described. Of the species of *Pancratium* given in Chapman's Flora, there can be little doubt that neither *P. maritimum* nor *P. nutans* will be found within our limits. The original *P. Carolinianum* of Linnæus (founded on Catesby's figure) was probably *Hymenocallis rotata*, and all later figures and descriptions of "*P. Carolinianum*" were based upon the foreign *P. maritimum*. It is probable that *Pancratium*, as now understood, and *Ismene* are not represented in our flora.

Brodiæa Howellii. Resembling large forms of *B. lactea:* stem nearly 2 feet high: flowers larger (9 or 10 lines long and about equalling the pedicels), purplish, turbinate-campanulate, the tube somewhat longer than the lobes: outer filaments short and deltoid; the inner longer, broadly winged the whole length, the wing truncate or

rounded above; anthers 2 lines long: capsule long-stipitate, oblong, attenuate upward; cells about 6-seeded. — Klickitat County, Washington Territory; Joseph Howell, June, 1879.

LILIUM GRAYI. See page 256. Since the preceding pages were in type, flowering specimens of this species have come to hand, collected (June 20) on the sides of Roan Mountain by Dr. Gray and Prof. C. S. Sargent. These show a nearer approach in some respects to *L. Canadense*, the leaves being narrower than in the original specimens and the flowers (1 to 3) are somewhat nodding, but still less decidedly pendent when open than is the usual habit of *L. Canadense*. The flowers are smaller (1½ to 2 inches long), but broader at base, the segments broader in proportion to the length and more abruptly contracted into the terminal cusp, deeply colored and but slightly spreading. The root is similar to that of *L. Canadense* and *L. superbum*.

LUZULA CAROLINÆ. Very slightly villous: stem a foot high or more, with broad flat leaves and a foliaceous bract exceeding the diffuse and lax cyme: flowers solitary on slender pedicels: anthers linear, about equalling the filaments: capsule with narrowly ovate valves, 1½ lines long, a little longer than the light-brown perianth: seed brown, subglobose, with a narrow whitish somewhat wing-like rhaphe. — On Grandfather Mountain in North Carolina; Gray and Carey, July, 1841. Differing from *L. pilosa* in its smoothness, the conspicuous bract, narrower capsule, and smaller seed without the prominent terminal twisted appendage.

LUZULA DIVARICATA. Usually low (6 inches high or less), and resembling *L. spadicea*, var. *parviflora*, except that the cyme is broadly diffuse with divaricately spreading branches and pedicels, and the seed is light-colored with a small appendage at base. — In the Sierra Nevada, mostly alpine, from above Mono Lake to Sierra County; W. H. Brewer (n. 1794, 2069, 2334), Rev. E. L. Greene, and J. G. Lemmon.

JUNCUS ROBUSTUS. Terete scape and leaves 2 to 5 feet high, very stout, rigid and pungent; the sheathing bases narrowed gradually above: lateral panicle compound with very unequal branches, erect and strict, usually 3 to 6 inches long and about equalling the scape; spathes and bracts long-acuminate, equalling or exceeding the flowers: clusters 2–4-flowered: outer perianth-segments broadly lanceolate, acute, the inner obovate and deeply emarginate, a line long: capsule subglobose, narrowed below, rounded at the summit, apiculate, brown, nearly 2 lines long: seeds acute at each end or slightly caudate, very finely ribbed, about a half-line long. — *J. acutus*, Engelm. Proc. St.

Louis Acad. 2. 438. *J. acutus*, var. *sphærocarpus*, Engelm. in Wheeler's Rep. 6. 376. Southern California, frequent in marshes in the Coast Ranges from San Francisco to San Diego. *J. acutus* of the Old World has a shorter and more spreading panicle, shorter spathes and bracts, a more triangular and more acute capsule, and usually more distinctly caudate seeds: the sheaths at the base are also more abruptly contracted. The tough scapes of the present species are split by the Indians and used in binding together the material of their baskets.

Juncus (Articulati) Nevadensis. Scape very slender from a slender horizontal rootstock, somewhat compressed, ½ to 2 feet high: leaves very narrow (rarely a line wide), subterete; ligules present: spathe short and very narrow: heads small, few to rather many in a short open panicle, frequently solitary: perianth-segments brownish, lanceolate, acuminate, 2 lines long: stamens 6; anthers longer than the filaments: stigmas long-exserted: capsule oblong, abruptly contracted into the stout style, which nearly equals the perianth: seeds minute, oblong, apiculate at each end. — *J. phæocephalus*, var. *gracilis*, Engelm. Proc. St. Louis Acad. 2. 473. Frequent in the Sierra Nevada, from Kern County (Rothrock) to Oregon. Resembling *J. articulatus* in habit, but much more slender; distinguished from *J. phæocephalus* by its slender habit, subterete scape and leaves, ligules, smaller heads, more abruptly acute capsule, and much smaller and narrower seeds.

Phyllospadix Torreyi. Stem and leaves much elongated, scarcely a line wide, the latter flat, faintly 1-nerved, with sheaths 2 to 10 inches long: spathes 2 to 6, near the summit of an elongated peduncle, the dilated portion 1½ or 2 inches long, foliaceous above: spadix enclosed, 1½ lines wide, with 15 to 20 ovate-oblong acute appendages within the margin and above the attachment of the corresponding ovaries, 2½ to 3 lines long: ovaries cordate-sagittate, somewhat flattened dorsally and carinate, 2½ lines long; stigmas half as long: fruit unknown. — Collected by Dr. Torrey at Santa Barbara, in flower. It is apparently the same that is described and figured by Ruprecht under the name of *P. Scouleri* (Mém. Acad. Petersb. 7. 58, t. 1 and 2, f. 5–16), from the mouth of Russian River, though represented with short peduncles, a single spathe and broader leaves. *P. Scouleri*, Hook. Fl. Bor.-Am. 2. 171, t. 186, may be distinguished by its ovate-oblong ovaries, rounded at base; its mature fruit is also unknown.

XVI.

A NEW RECEIVING TELEPHONE.

By Professor A. E. Dolbear.

Presented May 14, 1879.

There are two forms of receiving telephones in use, the more common being the magneto-telephone, the other a modification of the motograph invented several years ago by Edison. In the latter a diaphragm is made to vibrate by the varying friction between a metallic strip and a rotating cylinder of chalk that is saturated with some electrolytic substance. When a current of electricity is passed between these while the cylinder is rotated, the friction is found to be less as the current is greater, and hence a current varying with the phase of vibration of a sound-wave will give a like movement to a diaphragm properly connected to the strip pressing upon the cylinder.

It has happened to me to discover another method entirely different from either of these. Imagine a straight bar electro-magnet, two or three inches long, so mounted that the core may be rotated on its axis, the core to project half an inch beyond the bobbin on each end. Let an armature be made of a U form, the ends of the U to lie upon the projecting ends of the magnet. At the bend of the armature a short rod connects it to the vibrating plate of any sort, mica, or paper, or thin iron, mounted as in the ordinary way. Now, when a current of electricity is made to traverse the coil, the core becomes a magnet and the armature is attracted to it; if the core be rotated, the adhesion of the armature will carry the middle of the diaphragm towards the magnet, and if the current be stopped the elasticity of the plate will cause it to return to its original place. A vibrating current will thus set up corresponding vibrations in the diaphragm so long as the magnet turns.

The principle involved here may be readily put to the test by taking almost any form of an electro-magnet and coupling it in circuit with a

carbon transmitter or microphone. Tie to the thread from a common string telephone a nail or a screw two or three inches long, and let the latter hang over one pole of the magnet while the ear is applied to the open end of the tube. Let one at the transmitter talk, or make musical sounds, and they will be heard while the nail or screw is slowly dragged over the pole. The motion necessary for this is very small, two inches a minute being quite sufficient to produce the maximum effect with a magnet half an inch in diameter.

It is not essential, either, that the magnet should rotate, for if a strip of paper is put between the magnet and the armature and slowly pulled between them while the vibratory current passes, the sounds will be heard as before. Also, the same is effected by letting the armature project beyond the magnet, and rest upon a pulley of wood or other substance, which may be rotated as in the other cases.

With the instrument I exhibit I have heard talking at the distance of a foot from the ear, and musical sounds anywhere in a room thirty feet square, using a single bichromate cell and an Edison transmitter, the current being probably about one tenth of a Weber. I have named this instrument the *rotaphone*.

XVII.

CONTRIBUTIONS FROM THE CHEMICAL LABORATORY OF HARVARD COLLEGE.

RESEARCHES ON THE SUBSTITUTED BENZYL COMPOUNDS.

FIFTH PAPER.

PARACHLORBENZYL COMPOUNDS.

By C. Loring Jackson and J. Fleming White.

Presented March 12, 1879.

In the fourth paper of this series the necessity of a revision of all the so-called parachlorbenzyl compounds was pointed out, and the results were described, which had been obtained from the investigation of some of them by Mr. A. W. Field and one of us. This work is now finished, and we have the honor of laying before the Academy a description of the preparation and properties of the remaining parachlorbenzyl compounds, which have been heretofore made in an impure state, and also of a few related substances not as yet described.

Parachlorbenzylbromide melting-point, $48\frac{1}{2}°$ (made from pure paratoluidine), was used as the starting-point for these compounds, and therefore they cannot contain the isomeric impurities which caused the mistakes of our predecessors.

A comparison, in tabular form, of our more important results with the earlier ones, will be found at the end of the paper.

Parachlorbenzylsulphoacid, $C_6H_4ClCH_2SO_3H$.

This substance was first studied by Böhler,* whose paper, published in 1869, contains a description of the preparation of the potassium salt by heating chlorbenzylchloride with neutral potassic sulphite. It was, in fact, one of the papers coming from Strecker's laboratory to illustrate his general method of making sulphoacids,† first announced

* Böhler, Ann. Chem. Pharm. 154, p. 56.
† Strecker, Ann. Chem. Pharm. 148, p. 90.

in 1868. The salt was thus obtained in colorless needles which gave with baric chloride glistening crystals of $(C_7H_6ClSO_3)_2Ba \cdot H_2O$; the acid (made from the barium salt with sulphuric acid) formed when heated with an excess of plumbic hydrate, a basic lead salt, $(C_7H_6ClSO_3)_2Pb \cdot PbO_2H_2$, crystallized in scales with a silvery lustre; while with less plumbic hydrate a neutral salt was obtained, which, however, he did not analyze. All these salts were made from ordinary chlorbenzylchloride, and must therefore have been contaminated with the corresponding ortho compounds, as indeed was proved by Vogt and Henninger,* who took up the subject again in 1872, and by fusing the potassium salt (made according to Böhler's method) with potassic hydrate obtained a mixture of salicylic and paraoxybenzoic acids. They did not try, however, to separate the para from the ortho compound, but contented themselves with analyzing Böhler's potassium and barium salts: for the first they found the formula $C_7H_6ClSO_3K \cdot H_2O$; it crystallized from water in concentric groups of large flat needles, from alcohol in pearly plates, lost its water of crystallization at 160°, and was decomposed at higher temperatures; their barium salt agreed in amount of water of crystallization and properties with that of Böhler, except that it crystallized in bunches of needles. In preparing their potassium salt Vogt and Henninger observed the formation of an insoluble substance which, purified by crystallization from alcohol, melted at 167° and had the formula $(C_7H_6Cl)_2SO_2$; from the mother-liquors small quantities of two other substances were obtained, melting at 149° and 185°, and apparently having the same composition; they supposed, therefore, that the main product (melting-point 167°) was a mixture of these, and called it chlorinated benzylosulphide, — a name which, according to our present nomenclature, would be altered to dichlorbenzylsulphone. For a revision of their work on this substance, see page 314.

In taking up the subject we followed the method of our predecessors, except that we used sodic instead of potassic sulphite,† which we made by saturating one half of a strong solution of sodic carbonate with sulphurous dioxide, and then adding to it the other half. After boiling this solution with parachlorbenzylbromide, in the proportion of one molecule of bromide to one of sulphite, in a flask with a return-cooler for seven hours, the smell of the benzylbromide had disappeared; the liquid was therefore allowed to cool, and the insol-

* Vogt and Henninger, Ann. Chem. Pharm. 165, p. 372.

† Potassic sulphite is to be preferred, however. See p. 309.

uble portion removed by filtration. This should have been the sulphone described by Vogt and Henninger, but it melted at about 55° instead of 167°, and a qualitative test showed that it contained no sulphur; from the smell it seemed to be an impure parachlorbenzylalcohol, formed by the action of the water on the bromide, and it was not thought worth while to investigate it farther. Although we have repeated the preparation of the sodium salt many times, we have never observed the formation of Vogt and Henninger's sulphone, but have got invariably this substance with a much lower melting-point.

The *Sodium Salt*, $C_6H_4ClCH_2SO_3Na$, was purified by evaporating the filtrate from the insoluble substance just described to dryness, boiling the residue with absolute alcohol to remove the organic salt from the sodic bromide, and finally recrystallizing from a very little water by spontaneous evaporation.

1.8405 grs. of the salt dried in vacuo lost when heated to 160° 0.005 gr., corresponding to 0.27 per cent.

0.4160 gr. lost at 160° 0.002 gr., corresponding to 0.48 per cent.

As one molecule of water corresponds to 7.30 per cent, it is evident that the salt crystallizes without water, and the slight loss observed is due to a partial decomposition of the substance. This view is confirmed by the fact that the 1.8405 grs. used in the first experiment lost only 1 mgr. when the temperature was not allowed to go above 100°.

0.5650 gr. of the salt dried at 160° gave by the method of Carius 0.3512 gr. AgCl and 0.5804 gr. $BaSO_4$.

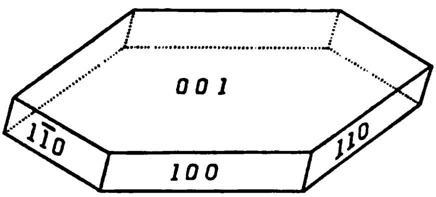
	Calculated for $C_7H_6ClSO_3Na$.	Found.
Chlorine	15.54	15.37
Sulphur	14.00	14.11

Crystallized from water it forms large flat colorless crystals with pointed ends; from alcohol, pearly scales; it is freely soluble in water, but only sparingly in alcohol.

Dr. F. A. Gooch, who has had the kindness to examine the substance crystallographically for us, reports that "the crystals did not admit of measurement with the goniometer; but an examination of some of the smaller ones, under the microscope, between crossed Nicols, proved them to be triclinic (see figure); the planes of polarization of the Nicols making, in the case of a crystal lying upon its basal plane angles of about 5° and 175°, or 85° and 95° respectively with the edge 100—001, when the plane of polarization of the ray from

the polarizer remains unchanged. The apparent angles of the adjacent edges, when the crystal lies upon its basal plane, are approximately as follows: —

Edge	100—001	upon edge	$1 1 0$—001	141°
"	100—001	" "	$1 \bar{1} 0$—001	147°
"	110—001	" "	$\bar{1} 1 0$—001	72°



The *Potassium Salt*, $C_6H_4ClCH_2SO_3K$, was made by adding potassic sulphate to the barium salt; the filtrate from the baric sulphate formed was evaporated to dryness, and the organic salt, dissolved out from the excess of potassic sulphate with absolute alcohol, purified by crystallization from water.

1.1328 grs. of the salt dried in vacuo lost when heated to 160° 0.0075 gr., corresponding to 0.66 per cent.

As one molecule of water corresponds to 6.85 per cent, it is evident that this salt, like that of sodium, is free from water of crystallization.

0.3000 gr. of the salt dried at 160° gave by the method of Carius 0.1760 gr. AgCl.

0.3165 gr. gave by the same method 0.3025 gr. $BaSO_4$.

0.3065 gr. gave, when heated with pure H_2SO_4, 0.1075 gr. of K_2SO_4.

	Calculated for $C_7H_6ClSO_3K$.	Found.
Chlorine	14.50	14.50
Sulphur	13.08	13.13
Potassium	15.98	15.75

It resembles the sodium salt closely in appearance, but is much more soluble in alcohol. As, therefore, the separation of this salt from potassic bromide would be easier than that of the corresponding sodium compounds, it is better in making a salt of the sulphoacid from parachlorbenzylbromide to use potassic in place of sodic sulphite.

To prepare the other salts of the parachlorbenzylsulphoacid the mother-liquor of the sodium salt was treated with a small quantity

of a solution of plumbic acetate, which precipitated plumbic bromide and sulphite; after these had been removed by filtration an excess of plumbic acetate threw down the lead salt of the sulphoacid, which was purified by recrystallization from water, and then decomposed with sulphuretted hydrogen; the filtrate from the plumbic sulphide was concentrated by evaporation, and the solution of parachlorbenzylsulphoacid thus obtained used in the preparation of the following salts.

The *Barium Salt*, $(C_6H_4ClCH_2SO_3)_2Ba \cdot 2H_2O$, was made by boiling the acid with pure baric carbonate. It can also be prepared by the addition of baric chloride to the sodium salt, but in this case it was found hard to free it from the excess of baric chloride.

0.9290 gr. of the salt dried in vacuo lost when heated to 160° 0.0565 gr.

0.5408 gr. lost 0.0332 gr.

	Calculated for $(C_7H_6ClSO_3)_2Ba \cdot 2H_2O$	Found.	
Water	6.16	6.08	6.12

0.1575 gr. of the salt dried at 160° gave, after precipitation with dilute H_2SO_4, 0.0680 gr. of $BaSO_4$.

0.4620 gr. gave 0.1995 gr. $BaSO_4$.

	Calculated for $(C_7H_6ClSO_3)_2Ba$.	Found.	
Barium	25.00	25.38	25.39

It crystallizes from water in radiated bunches of white needles which are moderately soluble in water.

The *Calcium Salt*, $(C_6H_4ClCH_2SO_3)_2Ca \cdot 7H_2O$, was made by warming the aqueous solution of the acid with calcic carbonate, filtering and allowing the concentrated filtrate to evaporate spontaneously; it was purified by recrystallization from water.

0.5805 gr. of the air-dried salt lost in vacuo 0.1033 gr.; when heated to 160°, 0.0332 gr.; making in all 0.1365 gr.

0.9536 gr. lost in vacuo 0.1506 gr.; when heated to 160°, 0.0552 gr.; making in all 0.2058 gr.

	Calculated for $(C_7H_6ClSO_3)_2Ca \cdot 7H_2O$.	Found.	
Water	21.84	23.51	21.58

	Calculated for $(C_7H_6ClSO_3)_2Ca \cdot 2H_2O$.	Found.	
Water	7.39	6.96	6.87

The air-dried salt, therefore, contains seven molecules of water of crystallization, five of which it gives up in vacuo, while a heat of 160° is necessary to remove the whole of its water. The very high result of the first water determination was undoubtedly due to hygroscopic moisture in the air-dried salt.

0.6976 gr. of the salt dried at 160° gave, after precipitation with ammonic oxalate and ignition over the blast-lamp, 0.085 gr. of CaO.

	Calculated for $(C_7H_6ClSO_3)_2Ca$.	Found.
Calcium	8.87	8.70

It forms rhombic crystals so nearly square that they look like flattened cubes, freely soluble in water.

The *Copper Salt*, $(C_6H_4ClCH_2SO_3)_2Cu \cdot 2H_2O$, was made by warming the aqueous solution of the acid with pure cupric carbonate, and concentrating the filtrate on the water-bath; the crystals thus obtained were recrystallized from water.

0.7400 gr. of the salt dried in vacuo lost when heated to 160° 0.0525 gr.

	Calculated for $(C_7H_6ClSO_3)_2Cu \cdot 2H_2O$.	Found.
Water	7.08	7.05

0.5000 gr. of the salt dried at 160° gave by precipitation with sodic hydrate 0.0833 gr. of CuO.

	Calculated for $(C_7H_6ClSO_3)_2Cu$.	Found.
Copper	13.37	13.30

It crystallizes in pale green needles grouped in bundles, and is readily soluble in water.

The neutral *Lead Salt*, $(C_6H_4ClCH_2SO_3)_2Pb \cdot H_2O$, was made by treating an aqueous solution of the acid with plumbic hydrate not in excess, the solution was evaporated in vacuo, and the crystals washed with a little water to free them from the acid. It is probable from the resemblance in crystalline form, that the precipitate formed on adding a strong solution of the sodium salt to plumbic acetate consists of this salt.

0.8695 gr. of the salt dried in vacuo lost when heated to 100° 0.0261 gr.

0.1910 gr. lost at 100° 0.0056 gr.

0.1900 gr. of the salt dried in vacuo gave, after precipitation with dilute H_2SO_4, 0.0902 gr. of $PbSO_4$.

	Calculated for $(C_7H_6ClSO_3)_2Pb.H_2O$.	Found.	
Water	2.83	3.00	2.93
Lead	32.55	32.43	

0.1742 gr. of the salt dried at 100° gave 0.0850 gr. of $PbSO_4$.

	Calculated for $(C_7H_6ClSO_3)_2Pb$.	Found.
Lead	33.50	33.34

It crystallizes in long white needles grouped in sheaves or stars, which are not freely soluble in water.

Two *Basic Lead Salts* were obtained by treating the mother-liquor from the preceding salt with an excess of plumbic hydrate; one crystallized from water by spontaneous evaporation in little spheres made up of radiating needles, and seemed to be free from water of crystallization, although it blackened and lost weight at 160°.

0.3384 gr. of the salt dried at 100° gave, after precipitation with dilute H_2SO_4, 0.2890 gr. of $PbSO_4$.

	Calculated for $(C_7H_6ClSO_3)_2Pb_3O_2$.	Found.
Lead	58.35	58.34

The formula of this salt is therefore $(C_6H_4ClCH_2SO_3)_2Pb_3O_2$. The second salt which crystallized from a hot concentrated solution in white scales had the formula $C_6H_4ClCH_2SO_3PbOH.H_2O$.

0.2128 gr. of the salt dried in vacuo lost at 120° 0.0087 gr.

0.2747 gr. of the salt dried in vacuo gave with dilute H_2SO_4 0.1870 gr. $PbSO_4$.

	Calculated for $C_7H_6ClSO_3PbOH.H_2O$.	Found.
Water	4.02	4.08
Lead	46.26	46.49

To obtain the *Free Acid* the lead salt, which had been purified with great care, was suspended in water, and decomposed with sulphuretted hydrogen, the filtrate from the plumbic sulphide formed was evaporated in a stream of sulphuretted hydrogen, first on the water-bath, and finally at a still lower temperature, until it had attained the consistency of syrup; it was then put in vacuo, where after standing some time it crystallized in square plates, which, however, soon turned yellow, while fumes were given off which smelt of hydrochloric acid and benzaldehyd. These yellow crystals melted at 108°, but the evidences of decomposition were so marked that we do not consider this the true melting-point of the acid, nor did it seem worth

while at present to follow the investigation of such an unstable substance farther.

The *Chloride*, $C_6H_4ClCH_2SO_2Cl$, was made by grinding the dry sodium salt with phosphoric pentachloride, and afterward warming the mixture gently in a porcelain dish on the sand-bath; the oily mass thus obtained gave with water the chloride as a heavy oil, which soon solidified, and was purified by crystallization from ether.

0.1410 gr. of substance gave by the method of Carius 0.1768 gr. of AgCl and 0.1470 gr. of $BaSO_4$.

	Calculated for $C_7H_6ClSO_2Cl$.	Found.
Chlorine	31.55	31.02
Sulphur	14.22	14.32

It forms white flattened crystals, often arranged in indistinct pennate groups, and having an aromatic odor; melting-point $85\frac{1}{2}°$; it is insoluble in water, soluble in ether and alcohol, but seems to be decomposed by the latter.

Parachlorbenzylsulphide, $(C_6H_4ClCH_2)_2S$.

Pauly * described this substance, which he obtained from chlorbenzylchloride (or bromide), by the action of an alcoholic solution of potassic sulphide, as a thick brown oil, with an unpleasant odor; and adds, that it did not solidify even after standing several days.

On warming an alcoholic solution of parachlorbenzylbromide with sodic sulphide (prepared by saturating one half of an alcoholic solution of NaOH with H_2S, and then adding the other half) we obtained by precipitation of the product with water a heavy oil, which we dissolved in hot alcohol; on cooling this saturated solution a purer oil separated, that solidified on standing over night, and was then purified by recrystallization from hot alcohol.

0.2760 gr. of the substance dried in vacuo gave on combustion 0.5970 gr. of Co_2 and 0.1110 gr. of H_2O.

	Calculated for $(C_7H_6Cl)_2S$.	Found.
Carbon	59.35	59.00
Hydrogen	4.24	4.47

It forms thick white needles, often seven centimeters long, with very little odor; from a hot alcoholic solution, it is sometimes depos-

* Pauly, Ann. Chem. Pharm. 167, p. 187.

ited as an oil, which solidifies by scratching with a sharp glass rod; melting-point, 42°; it cannot be sublimed without decomposition; essentially insoluble in water, soluble in cold, more freely in hot alcohol, easily soluble in ether, benzole, carbonic disulphide, and glacial acetic acid.

Diparachlorbenzylsulphone, $(C_6H_4ClCH_2)_2SO_2$, was made by adding the calculated amount of chromic anhydride in small quantities at a time to the preceding substance, both bodies being dissolved in glacial acetic acid; the product of the oxidation, washed with water until free from compounds of chromium, was purified by crystallization from alcohol. The substance was also formed by the oxidizing action of the air on parachlorbenzylsulphide.

0.3510 gr. of the substance gave, according to Carius, 0.3195 gr. of AgCl and 0.2610 gr. of $BaSO_4$.

	Calculated for $(C_7H_6Cl)_2SO_2$.	Found.
Chlorine	22.54	22.51
Sulphur	10.16	10.21

It crystallizes in very small needles, melts at 165°, and cannot be sublimed without decomposition; it is essentially insoluble in water, readily soluble in alcohol, ether, carbonic disulphide, glacial acetic acid, and ligroine. The melting-point of this substance (165°) is essentially the same as that of the sulphone (167°), obtained in largest quantity by Vogt and Henninger from the action of chlorbenzylchloride on potassic sulphite, and mentioned on page 307. The isomere, melting at 149°, obtained by them, was probably the corresponding orthochlorbenzylsulphone, but it is hard to understand what the substance melting at 185° could have been. It will be remembered that we did not succeed in obtaining a sulphone when we repeated their work.

Parachlorbenzylmercaptan, $C_6H_4ClCH_2SH$.

The first attempt to prepare this substance was made in 1860 by Beilstein,* who heated a somewhat indefinite mixture of dichlor-substitution products of toluol with potassic sulphydrate, and obtained an oil which on exposure to the air yielded well-formed octahedra with a vitreous lustre, melting from the first preparation at 77°–78°, from the second at 84°–85°. Later, Neuhof † tried the same experiment

* Beilstein, Ann. Chem. Pharm. 116, p. 336.

† Neuhof, Ann. Chem. Pharm. 147, p. 389.

with a mixture of ortho- and parachlorbenzylchloride, and confirmed the results of Beilstein, as the melting-point of his crystals was 84°–85°. In repeating their work, we found that on mixing alcoholic solutions of parachlorbenzylbromide and KSH (prepared by saturating an alcoholic solution of potassic hydrate with sulphuretted hydrogen), heat was given off, and the action was finished without the aid of external heat in about half an hour; on adding water to the product, a dark-colored oil was precipitated, which, purified by distillation with steam, was frozen by immersion in ice and salt, and recrystallized from alcohol with the aid of a freezing mixture.

0.2560 gr. of the substance dried in vacuo, treated by the method of Carius, gave 0.2276 gr. of AgCl and 0.3750 gr. of $BaSO_4$.

	Calculated for C_7H_6ClSH.	Found.
Chlorine	22.40	22.00
Sulphur	20.19	20.12

At ordinary temperatures, it is a colorless liquid with a most repulsive and nauseating smell; in a freezing mixture of ice and salt, it solidifies in white crystals, which melt from 19° to 20°. We are not certain that this is the true melting-point of the substance, as a small portion of it may have been converted into the disulphide by the action of the air, and the elementary analysis cannot show the presence of this impurity, but the number here given cannot be very far from the truth, as we got in no case a melting-point much above 20°, and the substance was reduced with zinc and dilute sulphuric acid, so as to convert any disulphide into mercaptan, before taking some of the melting-points. It distils with steam, and mixes readily with alcohol, ether, benzole, and carbonic disulphide, but not with water. Yellow mercuric oxide attacks it with great energy, and converts it into the following compound.

Parachlorbenzylmercaptid, $(C_6H_4ClCH_2S)_2Hg$, was purified by repeated crystallization from boiling alcohol.

0.4820 gr. of the substance dried in vacuo gave by precipitation with H_2S 0.2175 gr. of HgS.

	Calculated for $(C_7H_6ClS)_2Hg$.	Found.
Mercury	38.84	38.91

It forms light white needles without odor, which seem to have no definite melting-point, although the substance turns red or black, and shrinks to about one half of its original volume in the neighborhood

of 160°; it is insoluble in water, very slightly soluble in ether, benzole, carbonic disulphide, glacial acetic acid, and cold alcohol; more readily, but still not very freely, soluble in hot alcohol. It is decomposed by sulphuretted hydrogen into mercuric sulphide and the mercaptan.

Parachlorbenzyldisulphide, $(C_6H_4ClCH_2)_2S_2$.

This substance was made in several different ways: — (1.) When parachlorbenzylbromide was boiled for two or more days with an alcoholic solution of potassic sulphydrate, on evaporating off the alcohol a mixture of the oily mercaptan with needles of the disulphide was obtained, which was exposed to the air for some time to oxidize the mercaptan. (2.) The parachlorbenzylmercaptan was treated with the calculated amount of bromine dissolved in ether; the reaction is as follows: —

$$2C_7H_6ClSH + Br_2 = (C_7H_6Cl)_2S_2 + 2HBr.$$

When a large excess of bromine was added, the product was an oil with an aromatic smell, the study of which is postponed for the present. (3.) Parachlorbenzylbromide was warmed with an alcoholic solution of sodic disulphide (Na_2S_2) obtained by dissolving the calculated amount of flowers of sulphur in an alcoholic solution of sodic sulphide (Na_2S). The products of all these methods had the same melting-point and properties.

For analysis, a specimen prepared according to the first method was purified by crystallization from alcohol and dried in vacuo.

0.3925 gr. of the substance gave on combustion 0.7615 gr. of CO_2 and 0.1475 gr. of H_2O.

0.2540 gr. gave, according to the method of Carius, 0.3780 gr. of $BaSO_4$.

	Calculated for $(C_7H_6Cl)_2S_2$.	Found.
Carbon	53.34	52.91
Hydrogen	3.81	4.17
Sulphur	20.32	20.44

It forms flattened white needles with a disagreeable smell, somewhat like that of the mercaptan, but much less nauseating; melting-point 59°; insoluble in water, readily soluble in alcohol, glacial acetic acid and ligroine, very soluble in ether, benzole, and carbonic disulphide. Neither mercuric oxide nor mercuric chloride has any action upon it. Nascent hydrogen made from zinc and dilute sulphuric acid converts it into the mercaptan.

Beilstein, and afterward Neuhof, obtained their so-called mercaptan (melting-point 84°–85°) by boiling the substances together for a long time, which we find, as already stated, gives the disulphide as principal product; furthermore, their crystals were formed only after long exposure of the liquid product of the reaction to the air. It would seem, therefore, that their substance must have been the disulphide, the percentage composition of which is essentially the same as that of the mercaptan, and therefore the two substances could not be distinguished by analysis, but only by treatment with mercuric oxide, which they do not seem to have tried. On the other hand, the melting-point of their substance (84°) is much higher than that of ours (59°), and it is certainly strange that a mixture of an ortho- and para-compound should melt at a higher temperature than the pure para-compound; they also describe it as crystallizing in vitreous octahedra, while our substance crystallizes even by slow evaporation of a benzole solution in the flattened needles already mentioned.

Parachlorbenzyldisulphidedioxide, $(C_6H_4ClCH_2)_2S_2O_2$, was made by adding the necessary amount of chromic anhydride dissolved in glacial acetic acid to a weighed quantity of the disulphide also dissolved in glacial acetic acid; on the addition of water, an oil was deposited, which became solid on standing in the cold, and was purified by crystallization from alcohol.

0.5870 gr. of the substance dried in vacuo gave, by combustion, 1.0390 grs. CO_2 and 0.1838 gr. of H_2O.

	Calculated for $(C_7H_6Cl)_2S_2O_2$.	Found.
Carbon	48.42	48.27
Hydrogen	3.45	3.48

It is a waxy solid, which becomes crystalline after some time; the melting-point of the specimen analyzed was 120°; it is insoluble in water, readily soluble in alcohol, ether, benzole, carbonic disulphide, and glacial acetic acid.

The *Parachlorbenzylethylether* was made by boiling parachlorbenzylbromide with an alcoholic solution of sodic hydrate; the product was precipitated with water, and the oil purified by distillation with steam. It was a colorless liquid, which distilled over between 215°–225°, and did not solidify when cooled to —12°. As its properties therefore agreed essentially with those ascribed to it by

Naquet,* who made it as we did, and Neuhof,† who obtained it from the chlorbenzylacetate and alcoholic potassic hydrate, we did not think it worth while to analyze or study it more carefully.

We have thus brought our revision of the parachlorbenzyl compounds to an end; the only one previously obtained that we have not studied is the amide of the parachloralphatoluylic acid, which we did not succeed in obtaining by the action of potassic cyanide on parachlorbenzylbromide, although Neuhof made it in this way from the chlorbenzylchloride. It is possible, but not very probable, that this difference between his results and ours is due to the fact that he used the chloride while we used the bromide.

For convenience of comparison, the melting-points of the substances described in this paper, with those given by our predecessors, are collected in the following table, to which is added a comparison between the amounts of water of crystallization in the salts of the parachlorbenzylsulphoacid, in those heretofore described as such, and in the corresponding salts of the benzylsulphoacid.‡

COMPARISON OF MELTING-POINTS.

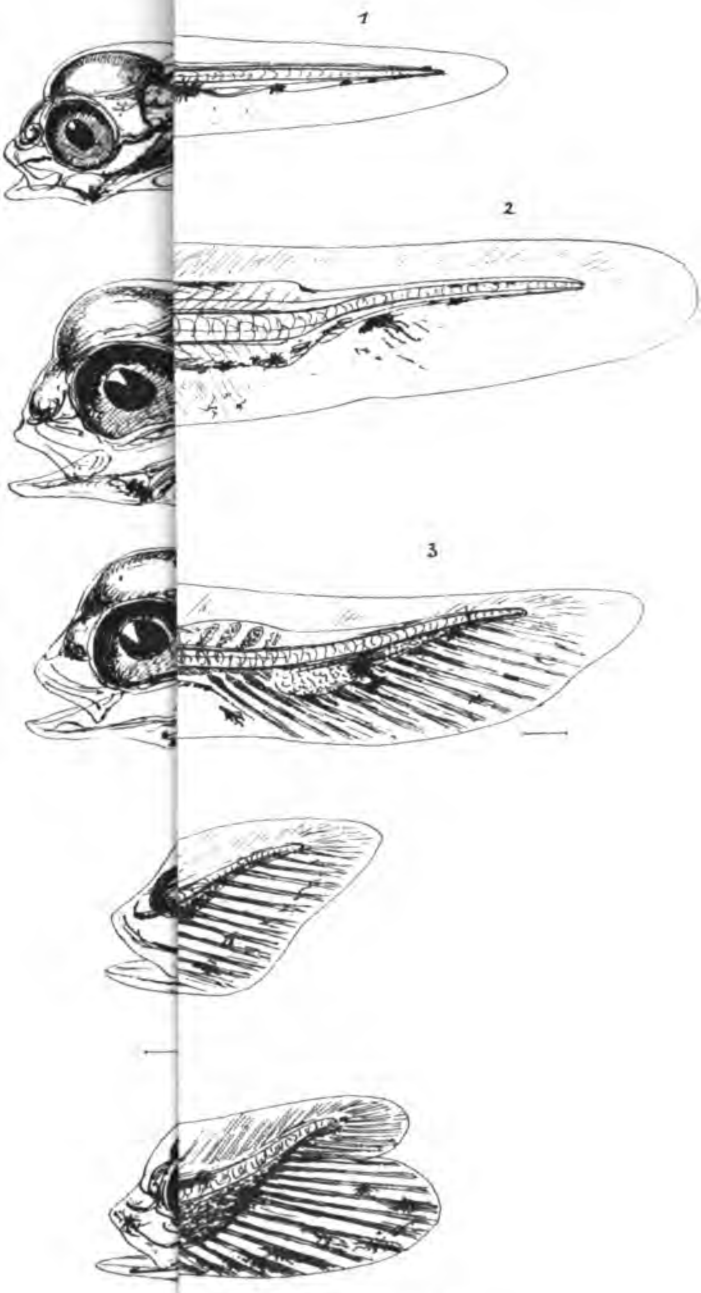
Formula of Substance.	Correct Melting-point.	Former Melting-point.	Authority for former Melting-point.
$C_6H_4ClCH_2SO_2Cl$	85½°		
$(C_6H_4ClCH_2)_2S$	42°	Oil	Pauly.
$(C_6H_4ClCH_2)_2SO_2$	165°	167°	Vogt and Henninger.
		77°–78°	Beilstein.
$C_6H_4ClCH_2SH$	19°	84°–85°	——
		84°–85°	Neuhof.
$(C_6H_4ClCH_2)_2S_2$	59°	See above.	
$(C_6H_4ClCH_2)_2S_2O_2$	120°		
$C_6H_4ClCH_2OC_2H_5$	Oil	Oil	Naquet.
		Oil	Neuhof.

* Naquet, Ann. Chem. Pharm., Supp. 2, p. 249.
† Neuhof, Ann. Chem. Pharm. 147, p. 339.
‡ Böhler, Zeitschrift der Chemie, 1868, p. 440.

COMPARISON OF THE COMPOSITION OF CERTAIN SALTS OF CHLORBENZYL AND BENZYL SULPHOACIDS.

Name of Salt.	Chlorbenzylsulphoacid.			Benzyl Sulphoacid.
	Para.	Böhler.	Vogt and Henninger.	
Sodium	No H_2O	—	—	—
Potassium	No H_2O	H_2O	H_2O	H_2O
Barium	$2H_2O$	H_2O	H_2O	$2H_2O$
Calcium	$7H_2O$ or $2H_2O$	—	—	$2H_2O$
Copper	$2H_2O$	—	—	No good crystals.
Lead	H_2O	—	—	No H_2O
Basic Lead	$PbO_2H_2 . 2H_2O$	PbO_2H_2	—	PbO_2H_2
Basic Lead	$2PbO$	—	—	—

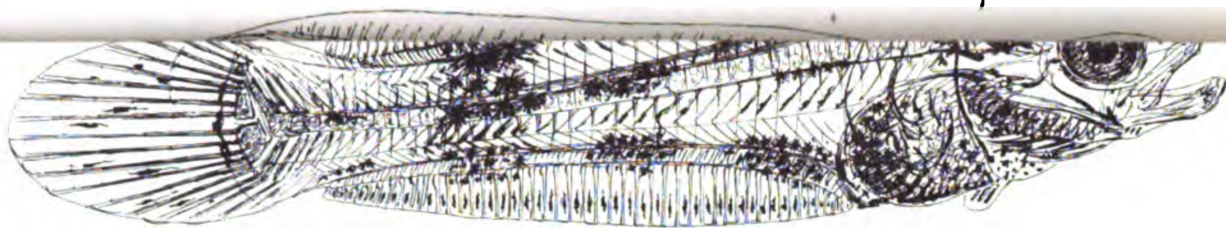
Alex. Agassiz Young Fishes Pl. III



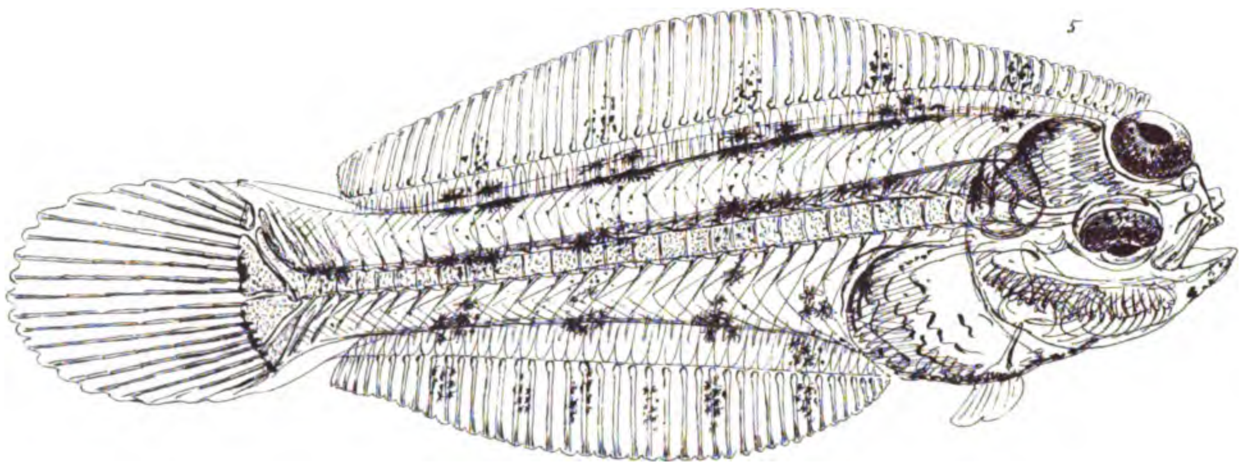
A. Ag. del

Alex Agassiz Young Fishes Pl. IV

1

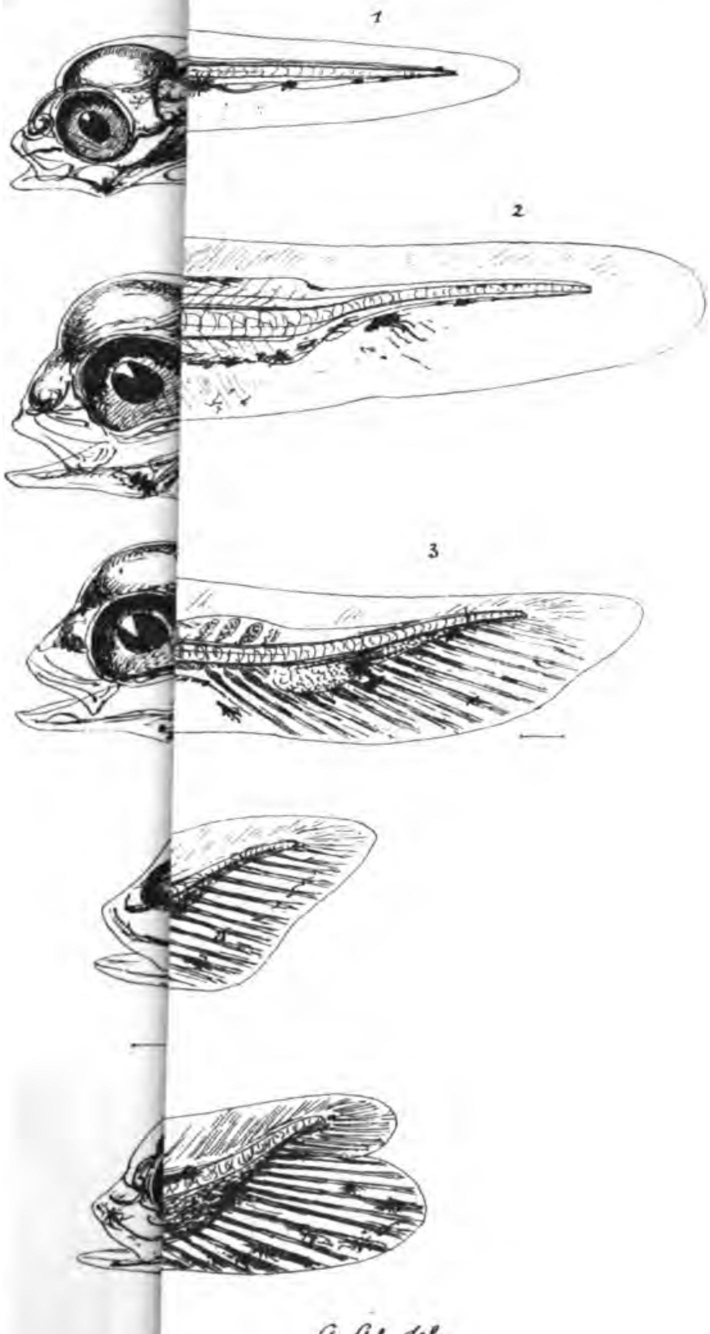


5



A. Ag. del.

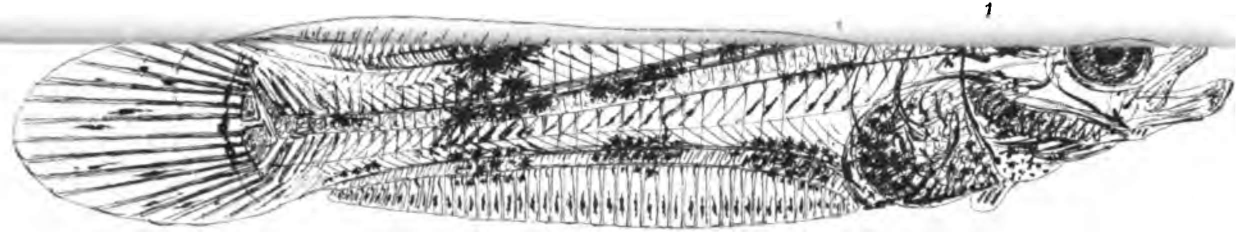
Alex. Agassiz Young Fishes Pl. III



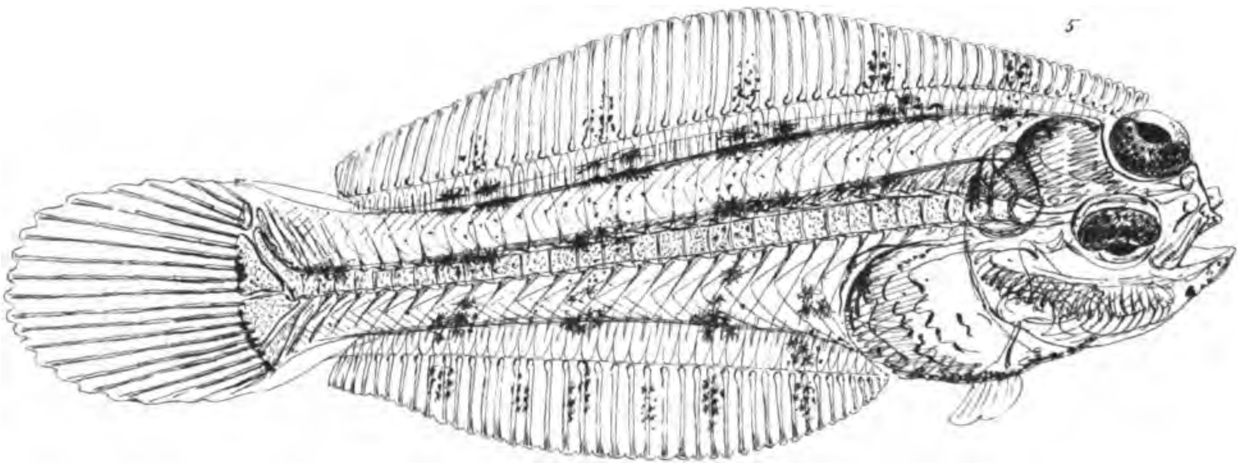
A. Ag. del.

Alex Agassiz Young Fishes Pl. IV

1

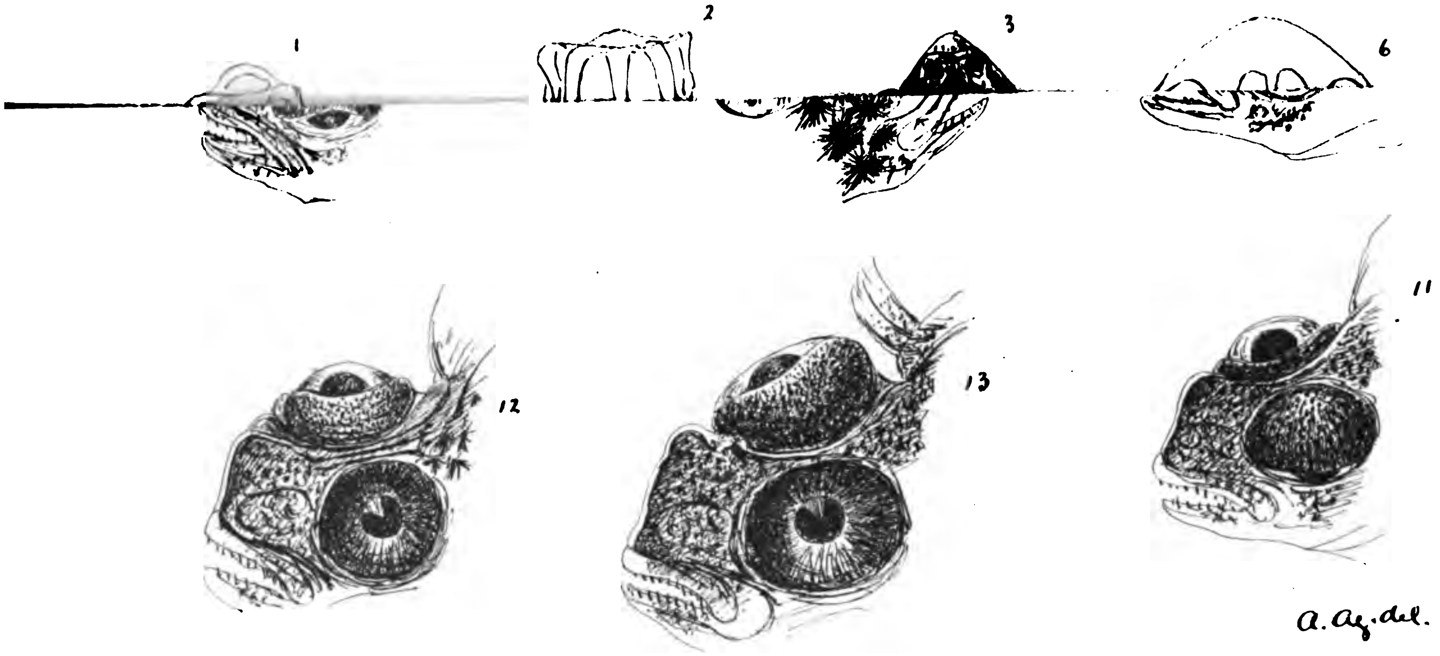


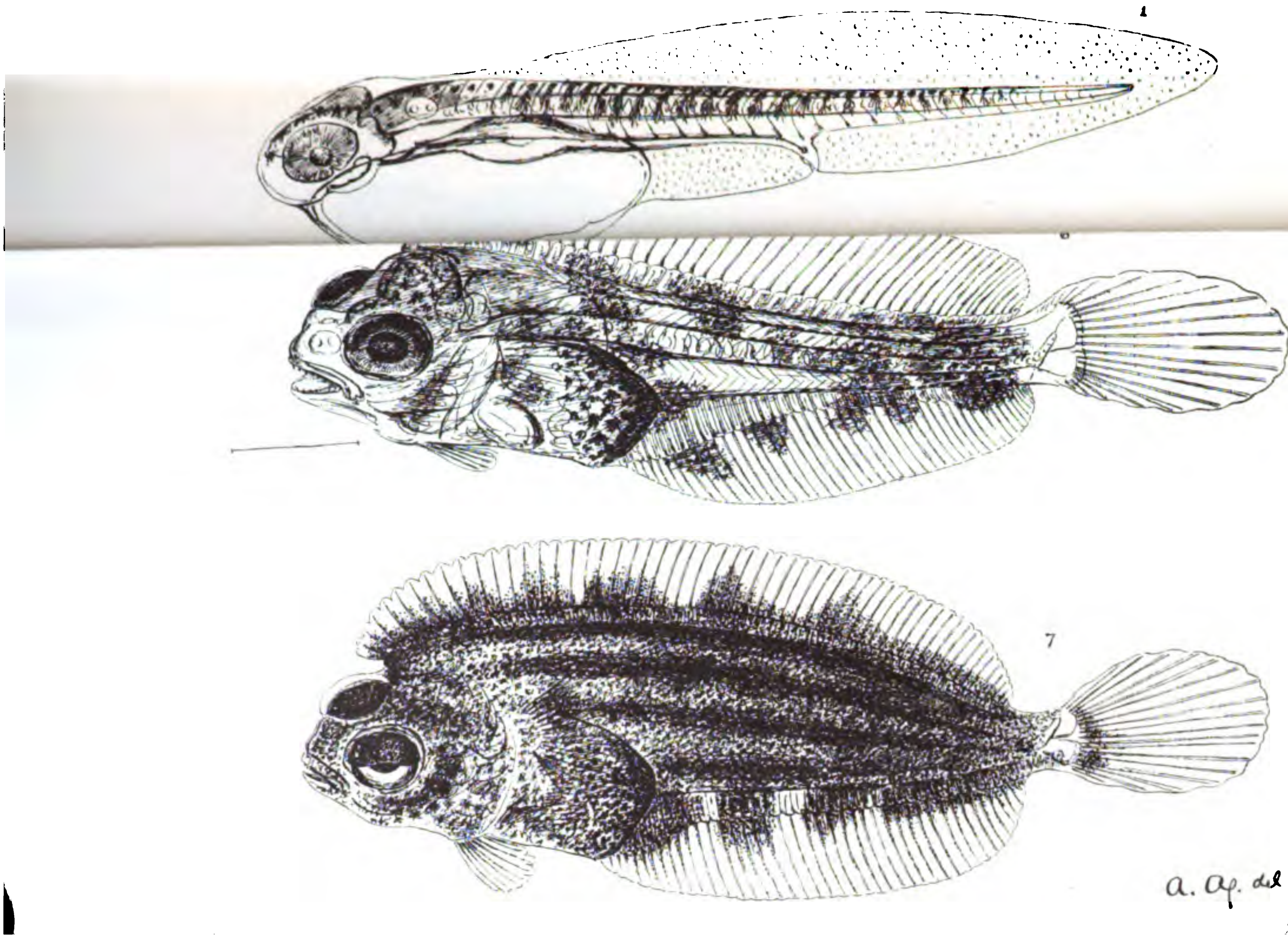
5



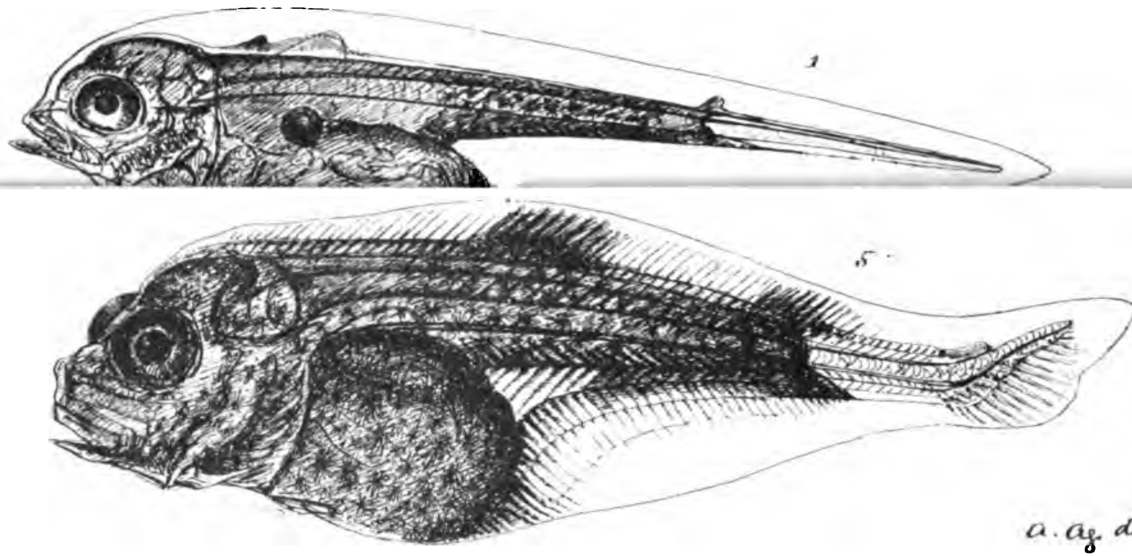
A. Ag. del.

Alex. Agassiz Young Fishes Pl. I

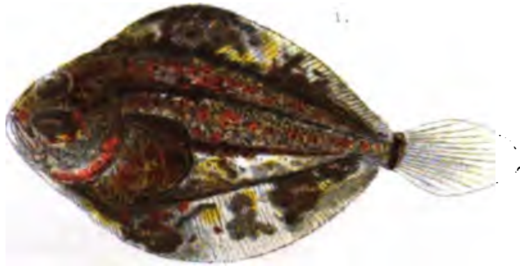


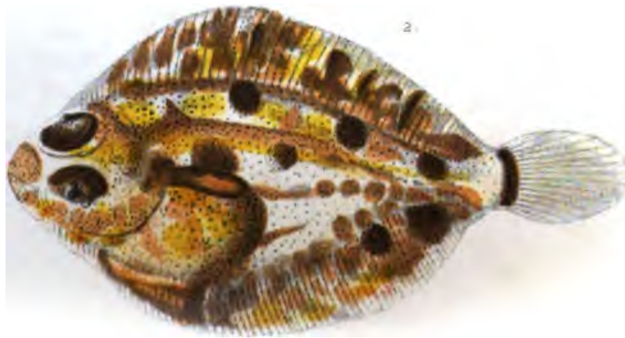

1
6
7
a. Ag. del.

Alex. Agassiz Young Fishes Pl. VII

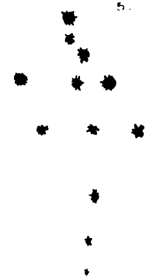


A. Ag. del.


1.


2.

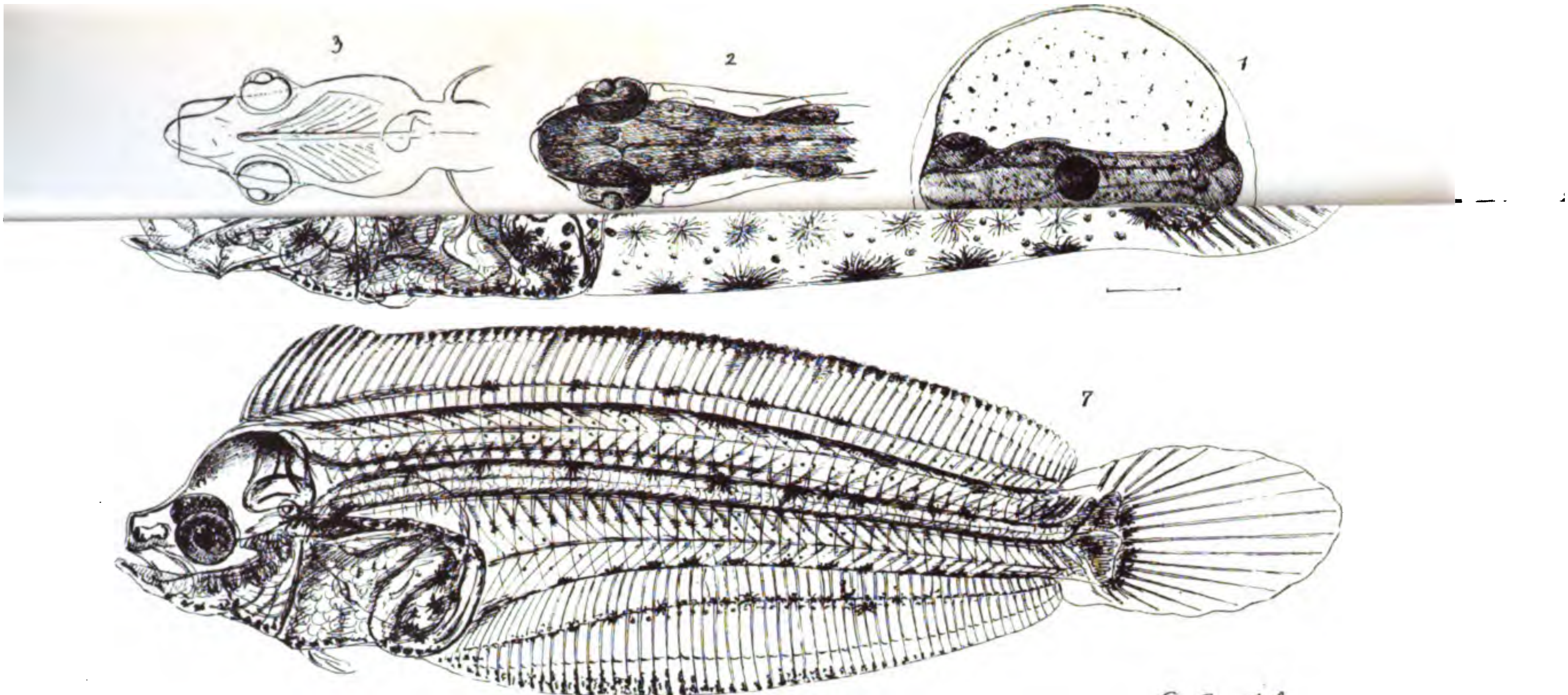

4.


5.


6.

A.Meisel,Lith

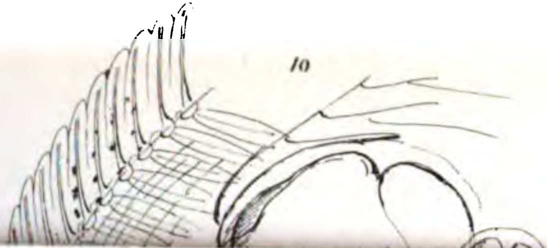
A.Ag del



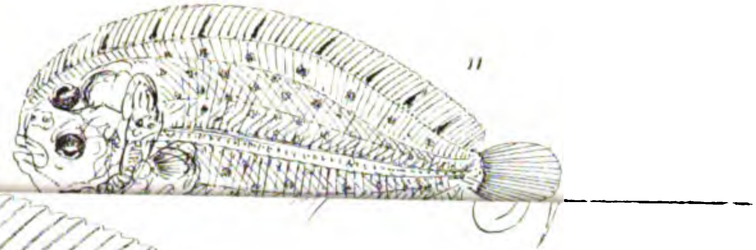
A. Ag. del.

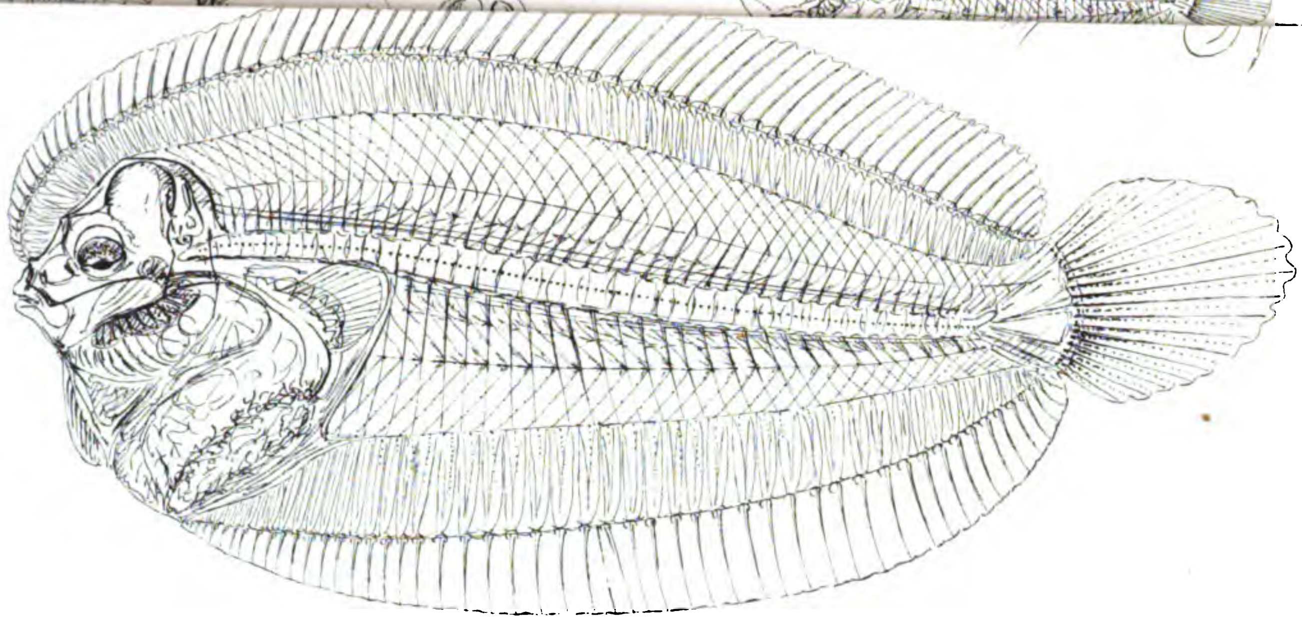
Alex. Agassiz Young Fishes Pl. X.

10



11





A. Ag. del.

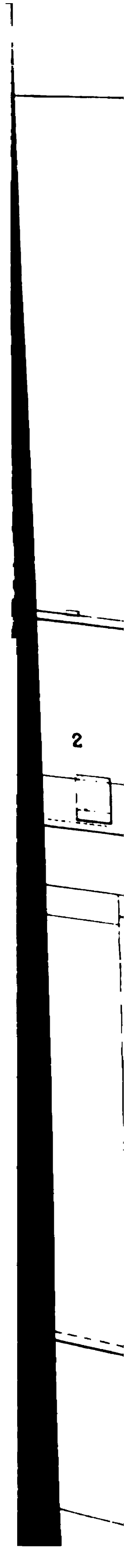
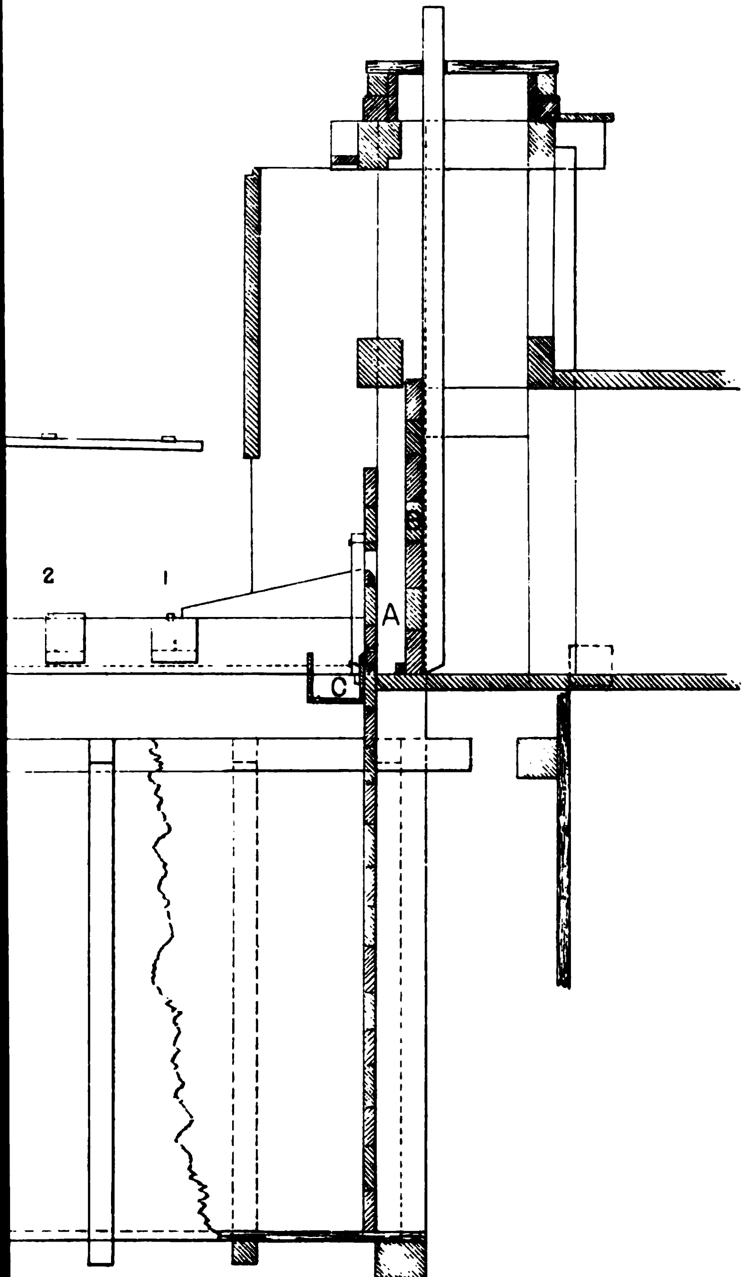

2

PLATE Nº 1.



SECTION

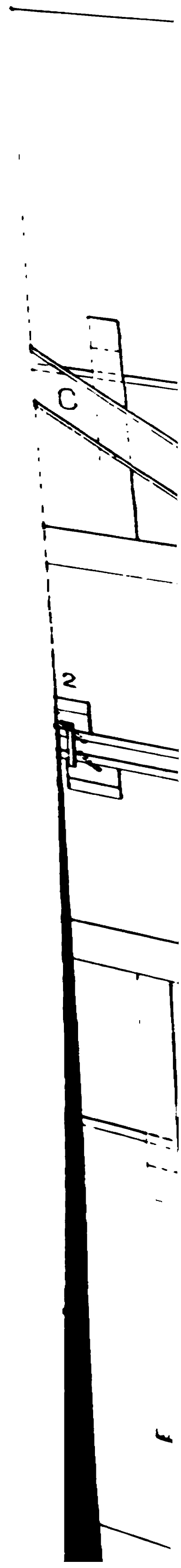
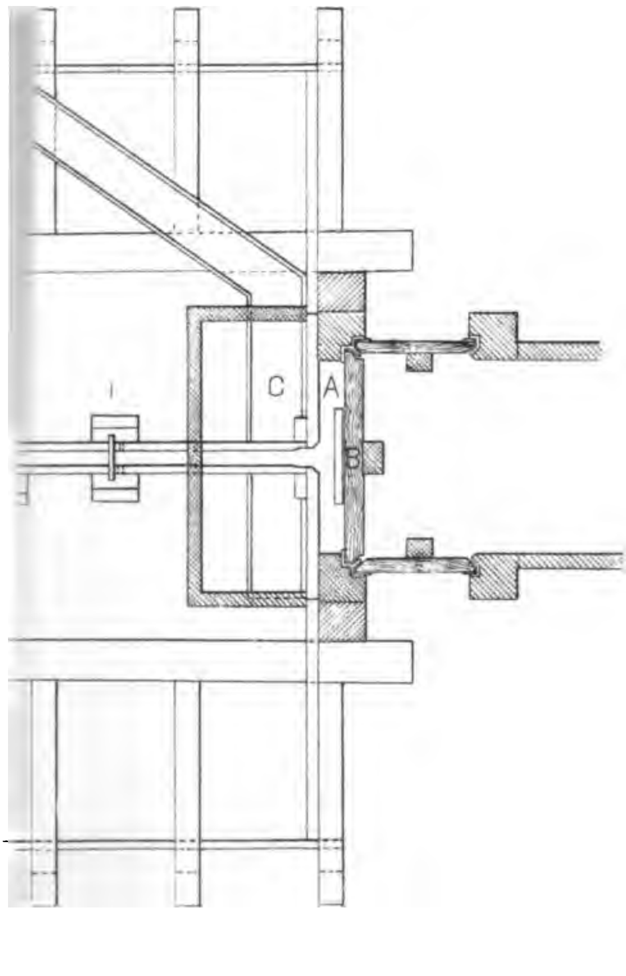

C
2

PLATE No 2



SCALE $\frac{1}{48}$

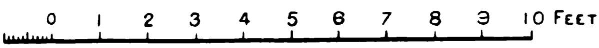


Photo Lith. G.W. & C.B. Colton & Co. N.Y.

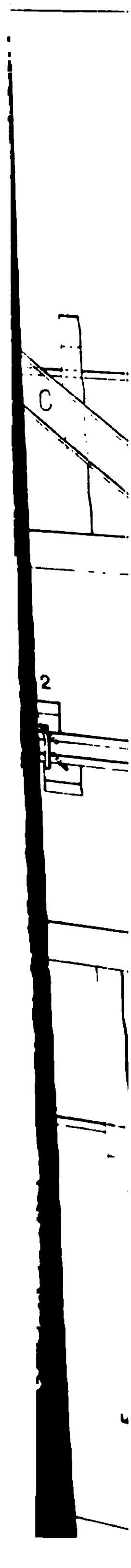
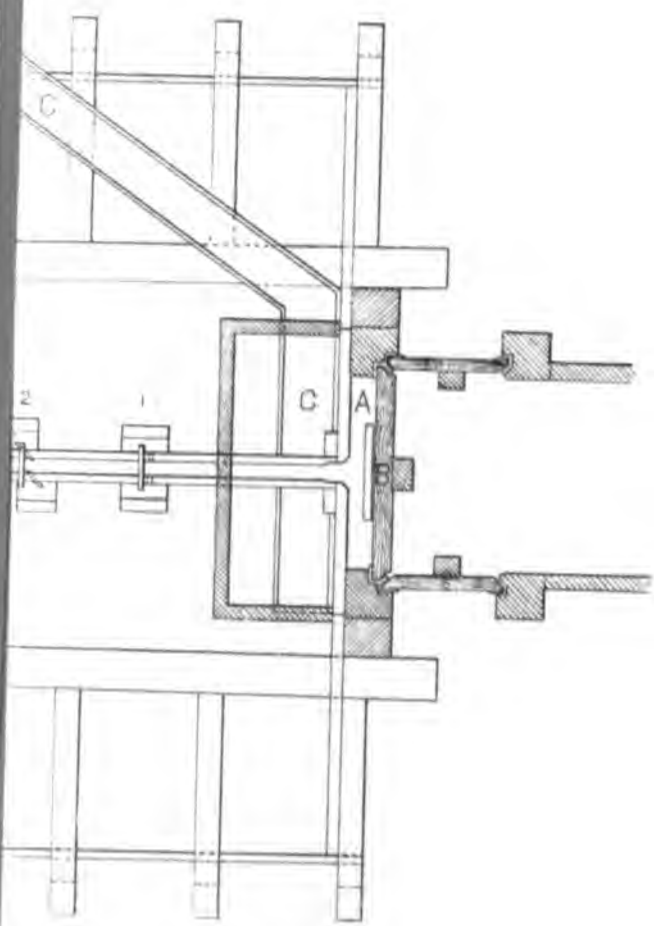

C
2

PLATE No 2

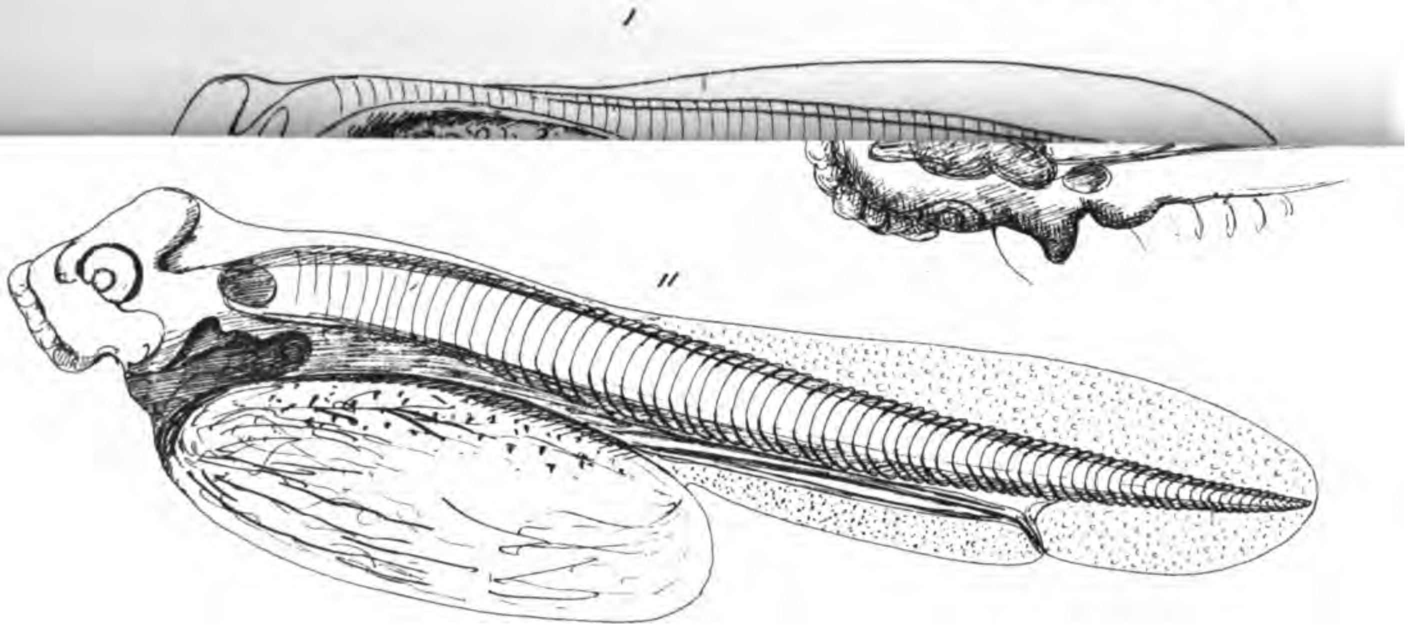


SCALE $\frac{1}{48}$

0 1 2 3 4 5 6 7 8 9 10 FEET

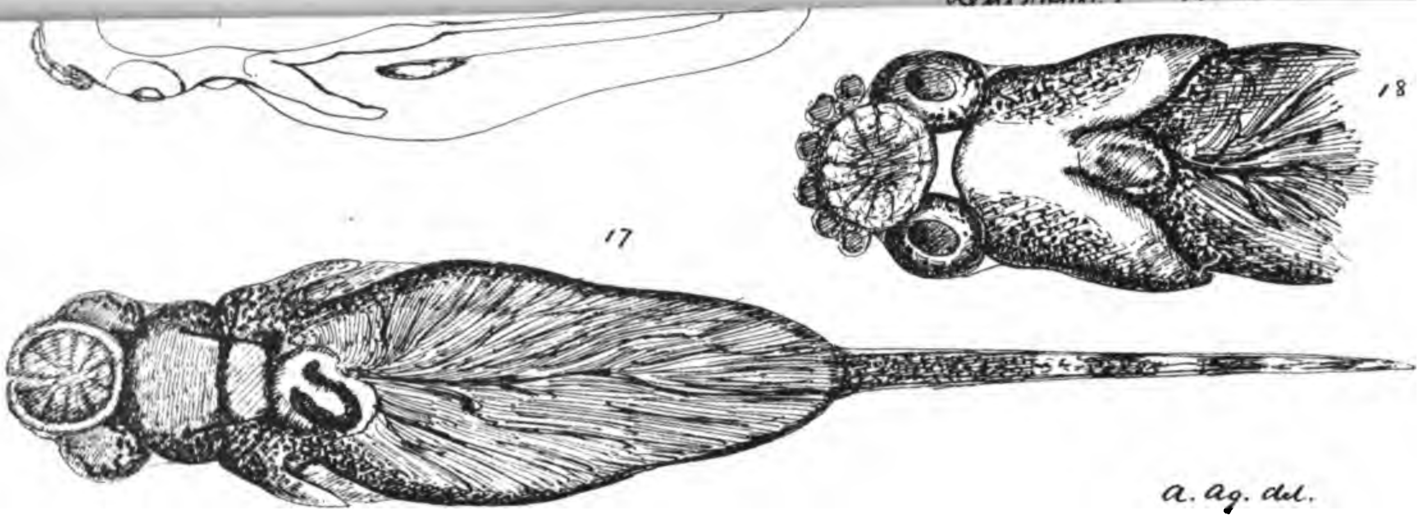
Photo-Lith. ... N.Y.

Lepidosteus Pl. I



a. Ag. del.

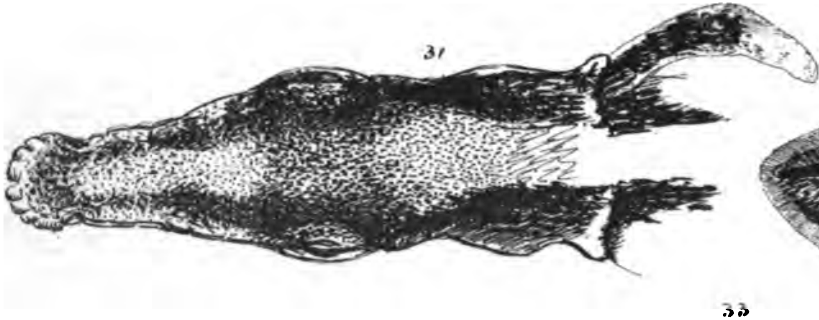
Lepidosteus Pl. II



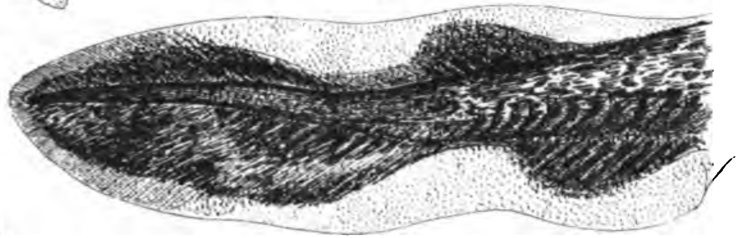
Lepidosteus Pl. III

19

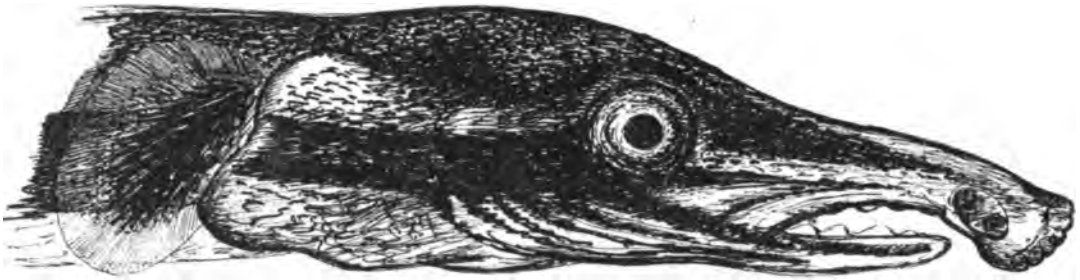
31



32

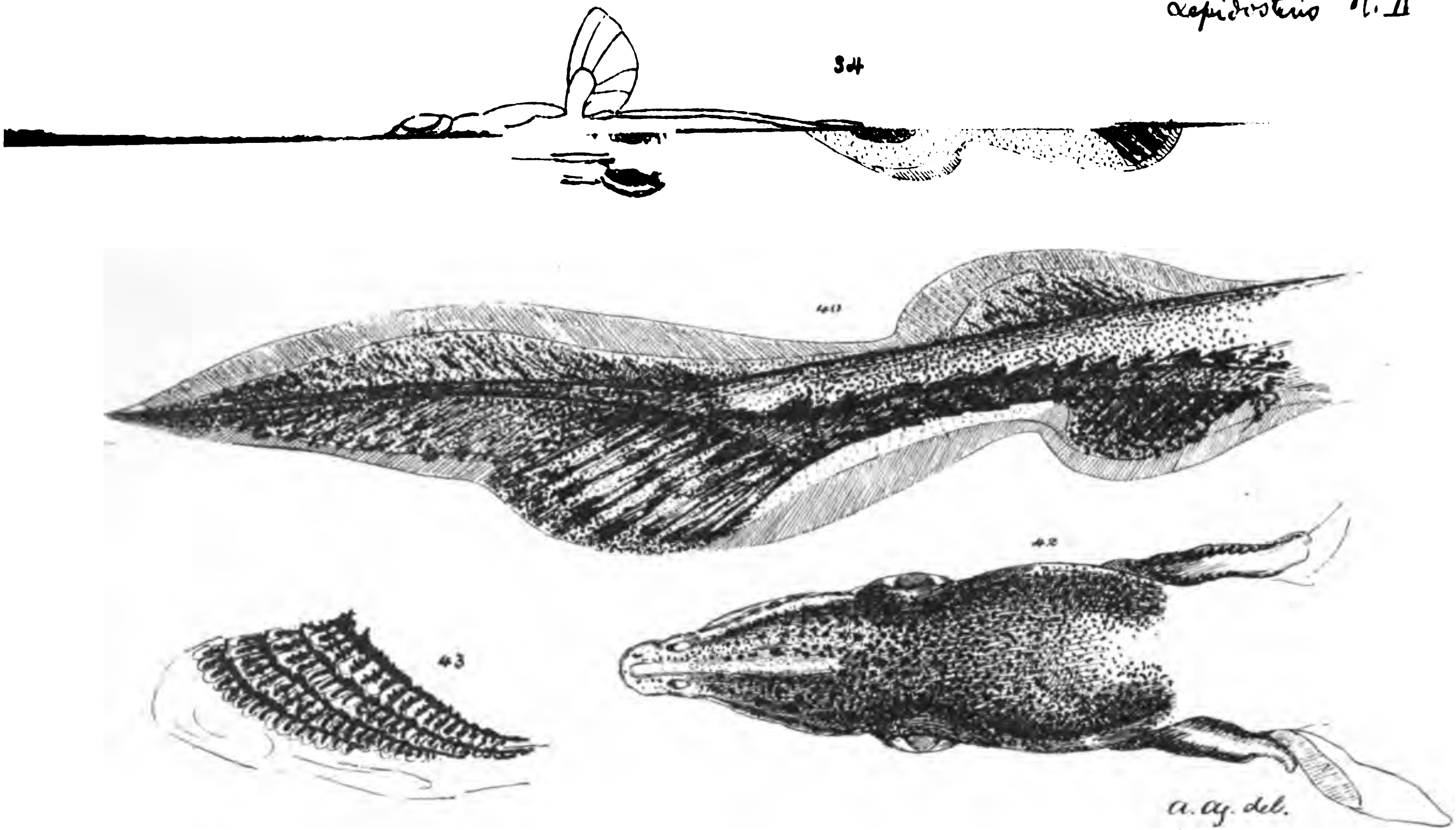


33



A. Ag. del.

Lépidosteus Pl. IV

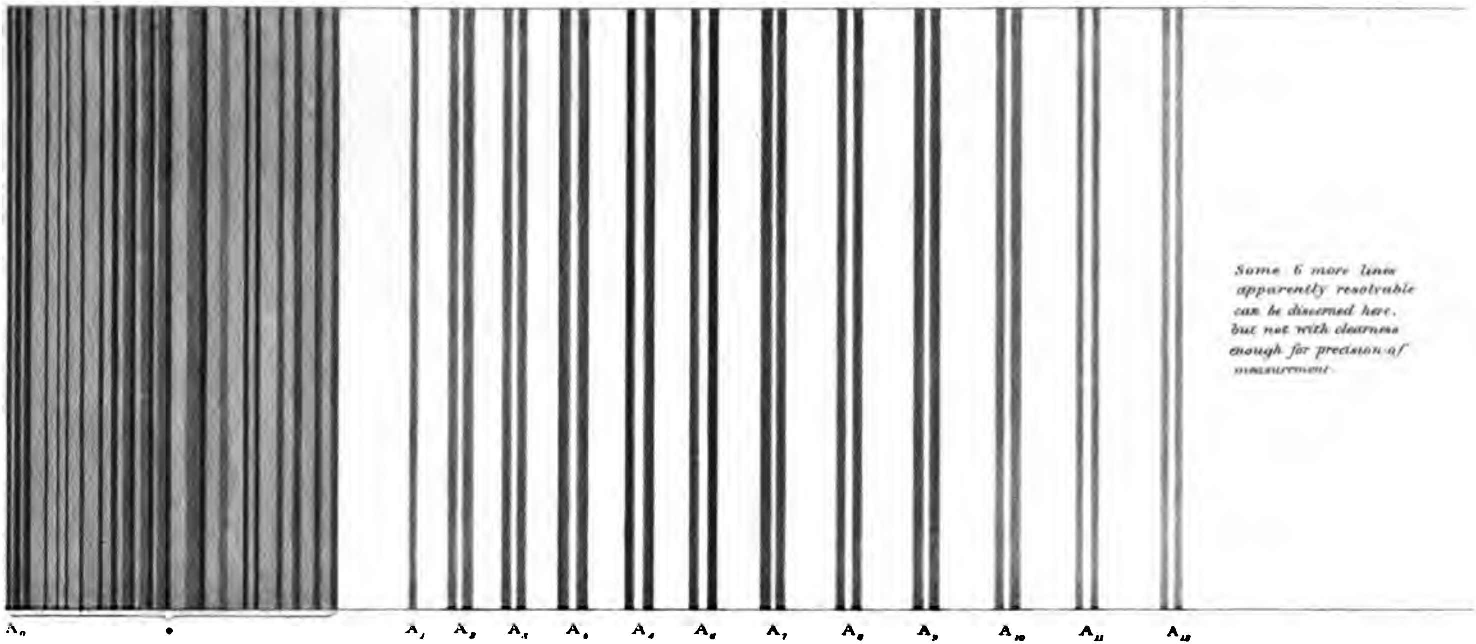


Lepidosteus Pl.V.

A. Ag. del.

A. Meisel Lith.

"A" GROUP

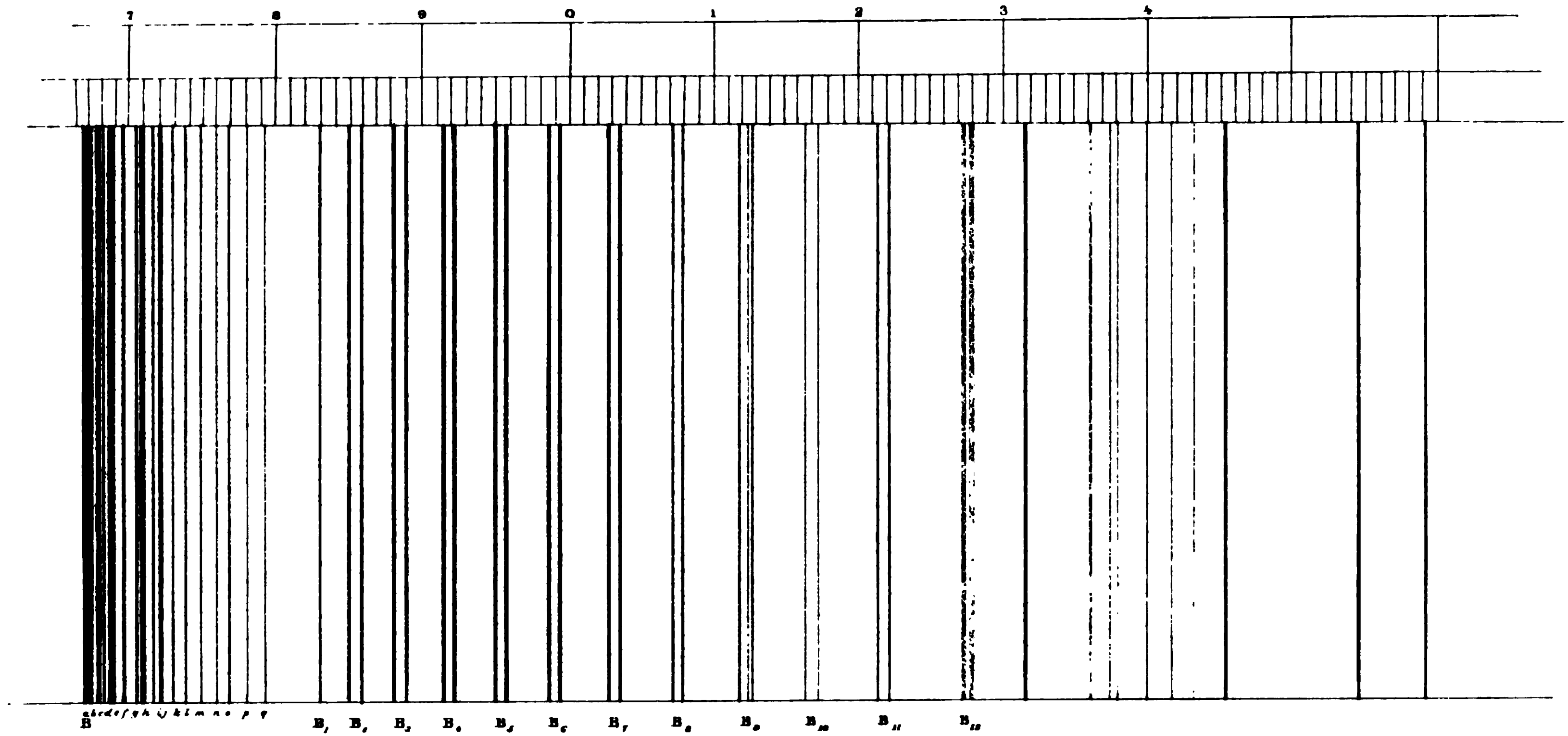


* *Note. the position of some of the lines in this wide band is uncertain, on account of the darkness of the field. It is not clear, how far the greater apparent width of the lines in the pairs than in those of "B" is real, and how far due to the need of a very wide slit.*

For Rumford Paper

S. P. Langley. Alleg^y Obs^y Oct^r 10 78.

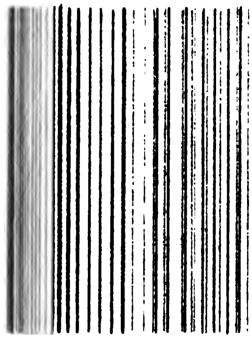
"B" GROUP

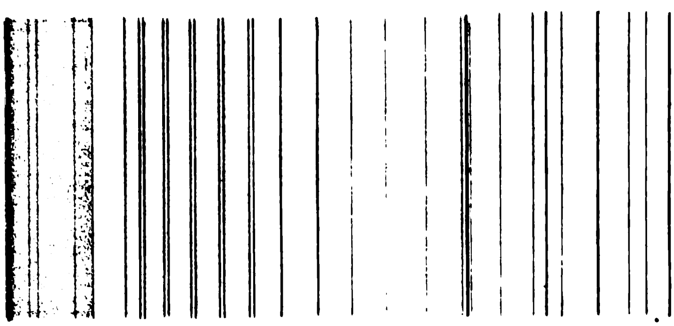


Rumford Pastor

S. P. Langley. Alleg.y Obs.y Oct. 10. 78.

"B" Group

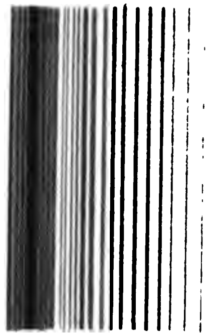


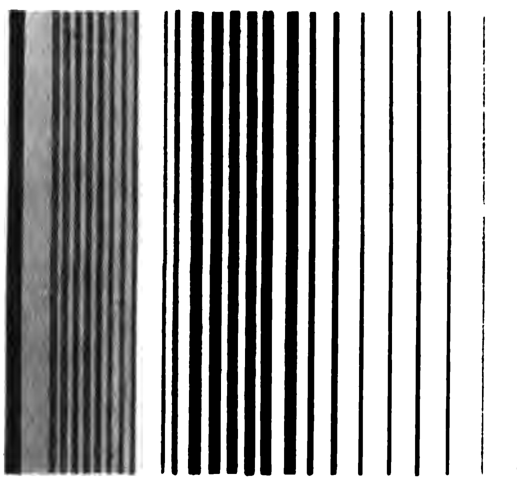


"B" Group *From Angstrom.*

FFS CHART.

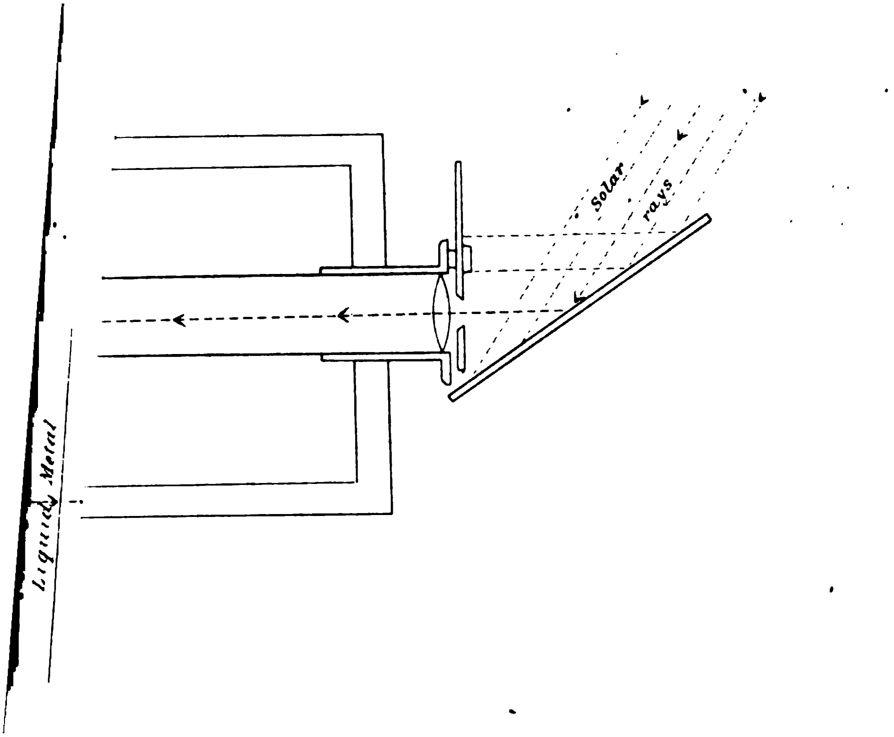
"A" Group

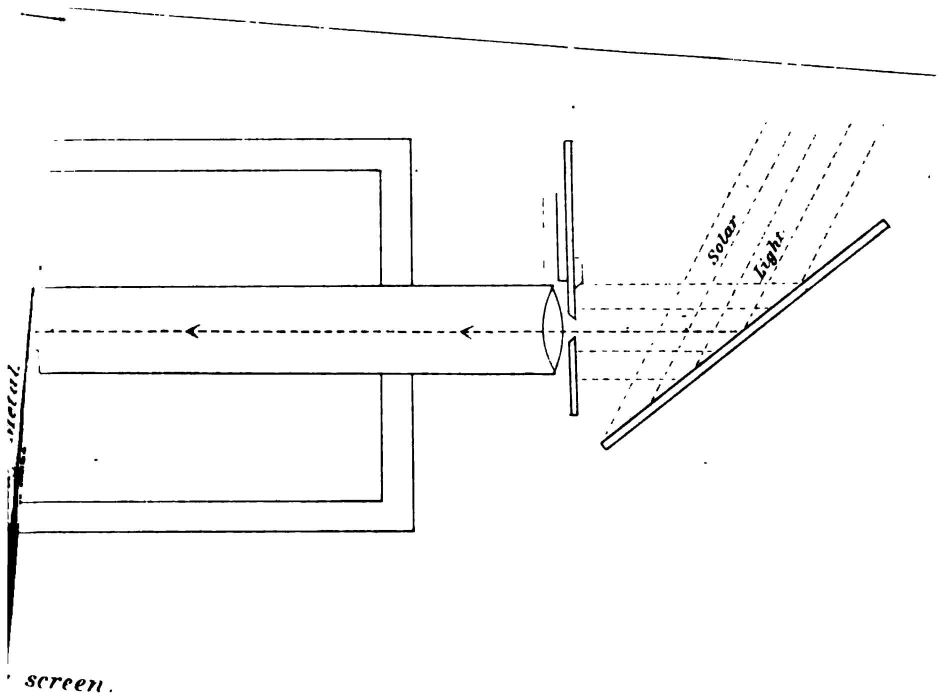




"A" Group From Smythe..

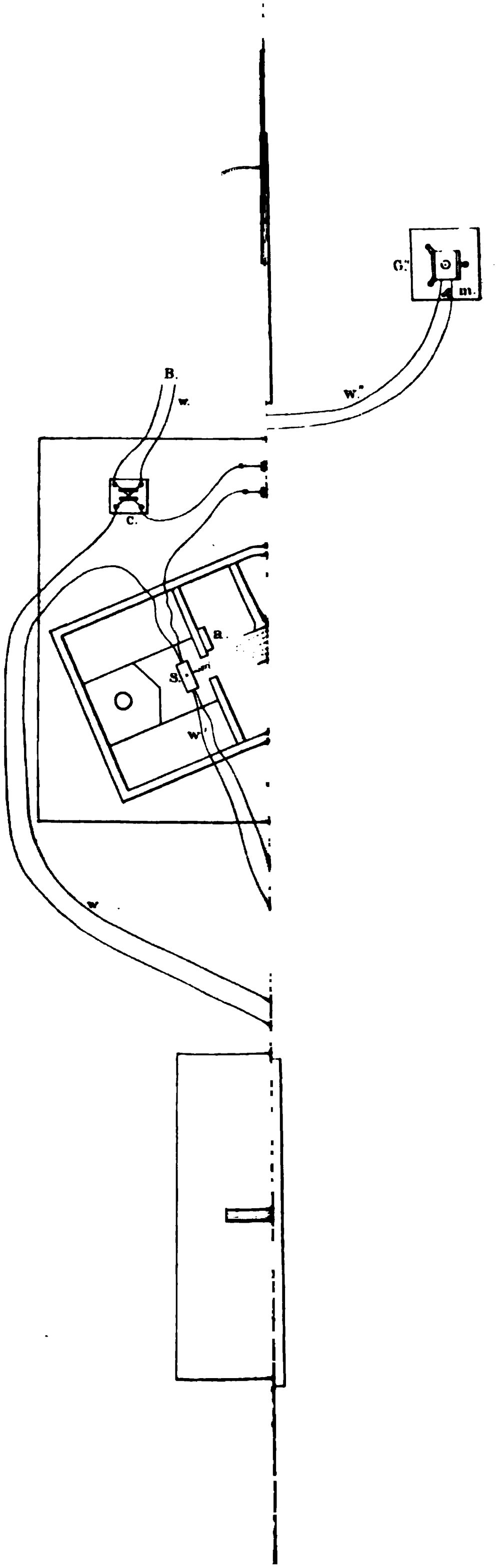
S.P Langley
Paper on A & B lines



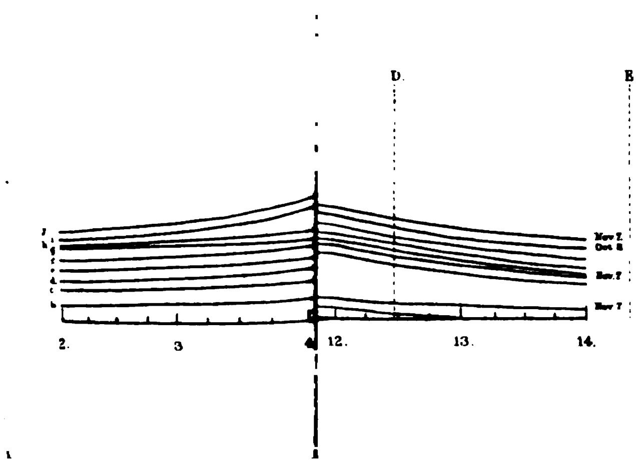


S. P. Langley.
Rumford Paper on
Solar Temperature.

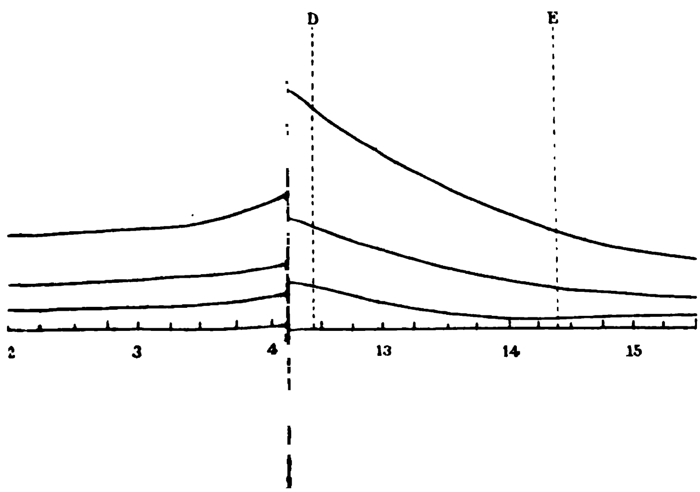
Pl. L



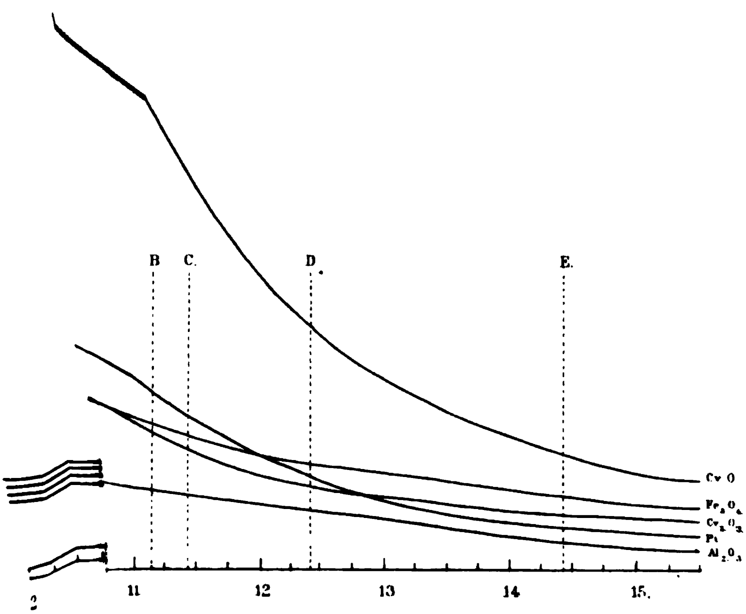
Pl. II



Pl. III.



Pl.IV.



PROCEEDINGS.

Seven hundred and twelfth Meeting.

May 28, 1878. — ANNUAL MEETING.

The PRESIDENT in the chair.

The Reports of the Corresponding Secretary, of the Librarian, and of the Treasurer were read.

On the motion of Professor Cooke, it was

Voted, That, when the Academy adjourn, it adjourn to the second Wednesday in June.

Voted, That a committee of ways and means be appointed to report, at the adjourned meeting, what appropriations can be safely made for the ensuing year.

The committee was constituted as follows: The Treasurer, the Corresponding Secretary, the Librarian, Professor Lovering, and Mr. Agassiz.

The chairman of the Rumford Committee read his annual report, and also presented the following vote: —

"At a meeting of the Rumford Committee, held May 24, it was

"*Voted*, To recommend to the Academy the appropriation of three hundred dollars ($300) to Professor Young, of Princeton, in aid of his observations of the solar eclipse of 29th July, 1878."

The annual election resulted in the choice of the following officers: —

CHARLES F. ADAMS, *President*.
JOSEPH LOVERING, *Vice-President*.
JOSIAH P. COOKE, JR., *Corresponding Secretary*.
JOHN TROWBRIDGE, *Recording Secretary*.
THEODORE LYMAN, *Treasurer*.
SAMUEL H. SCUDDER, *Librarian*.

Council.

Edward C. Pickering, James M. Peirce, John M. Ordway, } of Class I.

Benj. E. Cotting, Asa Gray, Alexander Agassiz, } of Class II.

Charles E. Norton, Robert C. Winthrop, Benj. F. Thomas, } of Class III.

Rumford Committee.

Wolcott Gibbs.
Edward C. Pickering.
John M. Ordway.
Stephen P. Ruggles.
John Trowbridge.
Josiah P. Cooke, Jr.
Joseph Lovering.

Member of Finance Committee.

Thomas T. Bouvé.

The Hon. Robert C. Winthrop presented the nomination book of the Academy of 1819.

On the motion of Professor Cooke, it was

Voted, That the thanks of the Academy be presented to Mr. Winthrop for the care he has taken in the preservation of Count Rumford's tomb, at Paris.

The following gentlemen were elected members of the Academy: —

Jacob Georg Agardh, of Lund, to be a Foreign Honorary Member in Class II., Section 2, in place of the late Elias Magnus Fries.

William Elwood Byerly, of Cambridge, to be a Resident Fellow in Class I., Section 1.

Charles Follen Folsom, of Boston, to be a Resident Fellow in Class II., Section 4.

Seven hundred and thirteenth Meeting.

June 12, 1878. — ADJOURNED ANNUAL MEETING.

Professor ASA GRAY was elected President *pro tempore.*

The Committees on Publication and on the Library were reappointed by the chair.

The committee on ways and means, through their chairman, Mr. Theodore Lyman, recommended the following appropriations for the ensuing year: —

For the Library	$500
For publishing	1,000

The appropriations were voted by the Academy.

On the motion of Professor Cooke, it was

Voted, That the rule of the Academy which furnishes a member one hundred extra copies of his paper be suspended for the ensuing year; and also, that all charges for correcting composition, over ten per cent, be charged to the author.

Mr. Scudder moved that the Academy take part in the proposed catalogue of periodical publications to be issued by the Librarian of Harvard College. No action was taken by the Academy.

The following papers were presented: —

"On the Embryology of the Gar Pike." By Alexander Agassiz.

"On a New Form of Electro-Dynamometer." By John Trowbridge.

"On Standard Measures." By William A. Rogers.

"On the Action of Bromine on Toluol and some of its Derivatives." By C. Loring Jackson and A. W. Field.

The following papers were presented by title: —

"On a Modification of Regnault's Air-Thermometer." By Josiah P. Cooke, Jr.

"On the Boiling Point of Iodide of Antimony." By Josiah P. Cooke, Jr. and W. C. Bennet.

"On Two New Forms of Micrometers." By Edward C. Pickering.

Seven hundred and fourteenth Meeting.

October 9, 1878. — STATED MEETING.

The PRESIDENT in the chair.

The following gentlemen were elected members of the Academy: —

James Barr Ames, of Cambridge, to be a Resident Fellow in Class III., Section 1.

John Chipman Gray, Jr., of Boston, to be a Resident Fellow in Class III., Section 1.

E. D. Leavitt, Jr., of Cambridge, to be a Resident Fellow in Class I., Section 4.

John Phillips Reynolds, of Boston, to be a Resident Fellow in Class II., Section 4.

Charles Sprague Sargent, of Brookline, to be a Resident Fellow in Class II., Section 2.

Thomas Carlyle, of London, to be a Foreign Honorary Member in Class III., Section 3, in place of the late Louis Adolphe Thiers.

H. A. J. Munro, of Cambridge, to be a Foreign Honorary Member in Class III., Section 2, in place of the late Count Paul Federigo Sclopis di Salerano.

John Ruskin, of Oxford, to be a Foreign Honorary Member in Class III., Section 4.

On the motion of Professor Cooke, it was

Voted, That, when this meeting adjourn, it adjourn to the second Wednesday in November, in order to vote upon nominations; and that the next meeting be an adjourned stated meeting.

The chair appointed Messrs. Lovering, Cooke, and Pickering to collect, sort, and count votes for a vacancy in the Council. Professor James B. Thayer was elected to fill the vacancy caused by the death of Judge Thomas.

The following papers were presented: —

"On the Limits of Accuracy in Measurements with the Microscope." By William A. Rogers.

"On a Standard Inch and a Standard Centimetre." By William A. Rogers.

"On Electric Lights and Methods of Testing the Strength of the Currents which produce them." By John Trowbridge.

Seven hundred and fifteenth Meeting.

November 13, 1878. — ADJOURNED STATED MEETING.

The PRESIDENT in the chair.

Professor Lovering reported from the Rumford Committee, that the funds appropriated to Professor C. A. Young, at the Annual Meeting, had not been required. He also presented two papers on the Sun, by Professor Langley, which were referred to the Publishing Committee.

Professor Lovering also presented the following report of the Rumford Committee: —

"*Voted*, To recommend to the Academy to appropriate from the income of the Rumford Fund, one hundred dollars ($100), to aid Mr. W. W. Jacques, of the Johns Hopkins University, in continuing his experiments on the distribution of heat in the spectrum."

The appropriation was voted.

The following gentlemen were elected members of the Academy: —

William Sumner Appleton, of Boston, to be a Resident Fellow in Class III., Section 2.

Henry Van Brunt, of Cambridge, to be a Resident Fellow in Class III., Section 4.

Henry Cabot Lodge, of Boston, to be a Resident Fellow in Class III., Section 3.

Henry Hobson Richardson, of Brookline, to be a Resident Fellow in Class III., Section 4.

Joseph S. Ropes, of Boston, to be a Resident Fellow in Class III., Section 3.

The following papers were presented: —

"On the Tides of the Gulf of Maine." By Henry Mitchell.

"Researches in Telephony." By Amos E. Dolbear.

Mr. N. D. C. Hodges, by invitation, described his new instrument for determining magnetic dip.

Professor Peirce discussed the results of Professor Mitchell's paper.

Seven hundred and sixteenth Meeting.

December 11, 1878. — MONTHLY MEETING.

The PRESIDENT in the chair.

The following papers were presented: —

"On the Determination of Equipotential Curves and Surfaces by the Telephone." By A. Graham Bell.

"On the Heat produced by the Magnetization and Demagnetization of Iron, Nickel, and Cobalt." By John Trowbridge.

Professor Bell gave a description of various ingenious appliances of M. Trouvé, of Paris. Remarks on this subject were made by Doctors Putnam and Williams.

Mr. Scudder called attention to a catalogue of the serial publications which are taken at the chief libraries in Boston and Cambridge.

Seven hundred and seventeenth Meeting.

January 8, 1879. — STATED MEETING.

The PRESIDENT in the chair.

The Corresponding Secretary read letters from Messrs. Ruskin, Carlyle, and Munro, accepting membership in the Academy.

On the motion of Mr. Winthrop, it was

Voted, That the chair nominate six members of the Academy who, together with himself, will constitute a committee of seven to consider the best manner of celebrating the one hundredth anniversary of the foundation of the American Academy of Arts and Sciences.

Professor Dolbear exhibited a new form of galvanometer and a new form of electric lamp.

On the motion of the Recording Secretary, it was

Voted, That the Academy adjourn to the second Wednesday in February, and that this meeting be an adjourned stated meeting.

Seven hundred and eighteenth Meeting.

February 12, 1879. — ADJOURNED STATED MEETING.

The PRESIDENT in the chair.

Mr. S. H. Scudder was appointed Secretary *pro tempore*.

Professor Lovering reported from the Rumford Committee a recommendation that the Academy appropriate one thousand dollars ($1,000) from the income of the Rumford Fund for investigations in light and heat, under the direction of the committee; and it was accordingly

Voted, To appropriate this sum from the Rumford Fund for the above-named investigation.

Professor Pickering made a communication on the Zone Observations of Harvard College Observatory; upon which remarks were made by Messrs. Watson and Rogers.

Professor Gray thought this a fitting opportunity for the Academy to express its satisfaction at the accomplishment of a work of such great and general utility; and, on his motion, it was

Voted, That the congratulations of the Academy be extended to the Director and to the Observer, Professor William A. Rogers, on the completion of the Zone Observations assigned to the Cambridge Observatory.

Professor Gray presented the following papers: —

"Some Remarks upon American Bryology, and Descriptions of some new Species of Mosses." By Leo Lesquereux and Thomas P. James.

"Characters of some new Genera and Species of Plants, chiefly of California and Oregon." By Asa Gray.

Mr. N. D. C. Hodges described a new galvanometer.

Professor Shaler read a short paper on explorations in coal mines. Remarks on this paper were offered by Messrs. Watson and Ordway.

Seven hundred and nineteenth Meeting.

March 12, 1879. — STATED MEETING.

The PRESIDENT in the chair.

The Chair named six additional members of the Centennial Committee, in accordance with the vote of the Academy at its meeting of January 8. The Committee was thus constituted as follows: —

Charles F. Adams, *Chairman*, Robert C. Winthrop, Asa Gray, John A. Lowell, Theodore Lyman, Josiah P. Cooke, Jr., and Benjamin E. Cotting.

The following papers were presented: —

"On the Degree of Reliability of Marey's Drum for Time Experiments." By James J. Putnam.

"On a Modified Pendulum Myograph." By James J. Putnam.

"On the Coefficient of Expansion of the Brass Bars used by the United States Coast Survey for Standards of Length." By William A. Rogers.

The following paper was presented by title: —

"On certain Parachlorbenzyl Compounds." By C. L. Jackson and J. Fleming White.

The following gentlemen were elected members of the Academy: —

Edward Atkinson, of Boston, to be a Resident Fellow in Class III., Section 3.

James Freeman Clarke, of Boston, to be a Resident Fellow in Class III., Section 1.

Frank Winthrop Draper, of Boston, to be a Resident Fellow in Class II., Section 4.

Alfred Hosmer, of Watertown, to be a Resident Fellow in Class II., Section 4.

Robert H. Richards, of Boston, to be a Resident Fellow in Class I., Section 3.

Asaph Hall, of Washington, to be an Associate Fellow in Class I., Section 2.

Viscount Ferdinand de Lesseps, of Paris, to be a Foreign Honorary Member in Class I., Section 4, in place of the late Urbain-Jean-Joseph Leverrier.

Franz Cornelis Donders, of Utrecht, to be a Foreign Honorary Member in Class II., Section 4, in place of the late Karl Freiherr von Rokitanski.

Professor Bowditch moved

That the Secretary be instructed, when notifying members of a meeting of the Academy, to communicate to them the names of candidates who are to be balloted for at said meeting.

That the above motion be assigned for discussion at the next meeting of the Academy.

Remarks upon the life and services of Doctor Jacob Bigelow were made by the President and by Professor Gray.

On the motion of Professor Bowditch, it was

Voted, That the Academy adjourn to the second Wednesday in April, and that the meeting be an adjourned stated meeting.

Seven hundred and twentieth Meeting.

April 9, 1879. — ADJOURNED STATED MEETING.

The PRESIDENT in the chair.

Professor B. Peirce read a paper on the Meteoric Constitution of the Solar System.

Professor E. C. Pickering described a new form of instrument for measuring the light of the stars.

The following papers were presented by title: —

"On the Distribution of Heat in the Spectra of Various

Substances raised to Incandescence." By W. W. Jacques, of Johns Hopkins University, Baltimore.

"On the Action of Bromine on Substituted Toluols." By Professor C. L. Jackson and Mr. A. W. Field.

Seven hundred and twenty-first Meeting.

May 14, 1879. — MONTHLY MEETING.

The PRESIDENT in the chair.

The Corresponding Secretary announced that he had received letters from T. W. Draper, of Boston, R. H. Richards, of Boston, H. H. Richardson, of Brookline, Asaph Hall, of Washington, T. C. Donders, of Utrecht, and F. de Lesseps, of Paris, accepting membership in the Academy.

Mr. R. C. Winthrop read the following report from the committee appointed to consider the best manner of celebrating the centennial of the Academy: —

"The committee appointed to report a plan for the commemoration of the Centennial Anniversary of the Academy next spring, recommend that a meeting of the Academy be arranged for some day in 1880, which shall be decided on as most suitable, at which a commemorative address or addresses shall be delivered by the President and any other members who may be selected for the purpose, and that it be followed by a social festival of such nature as shall hereafter be thought best; that in the mean time efforts be made to raise a centennial fund for securing a hall for the Academy, or for such other purposes as may be thought desirable; that the Secretaries, with such assistance as they may desire, prepare a history of the foundation, rise, and progress of the Academy, to be printed in connection with the account of the Centennial Celebration; and that, for the purpose of carrying out this programme, a committee of arrangements of members be appointed by the chair, with full powers."

Dr. H. P. Bowditch described a new form of Plethysmograph.

Mr. N. D. C. Hodges read, by invitation, a paper on the Dimensions of Molecules.

Professor Pickering described a new form of Nebula Photometer.

Professor Trowbridge read two contributions from the Physical Laboratory of Harvard College, with the following titles: —

"On the Vibration of Elliptical Plates."

"On a Method of Studying Wave Motion."

The following papers were presented by title: —

"Characters of New Species of Plants from Mexico, collected by Dr. E. Palmer and Dr. C. C. Parry." By Dr. Asa Gray.

"A Revision of the North American Liliaceæ, and Descriptions of some New Species of other Orders." By Mr. Sereno Watson.

"On Complex Inorganic Acids." By Dr. Wolcott Gibbs.

"On the Synthesis of Anthracene." By Professor C. Loring Jackson and Mr. J. Fleming White.

The meeting then dissolved.

REPORT OF THE COUNCIL.

MAY 27, 1879.

SINCE the last report, May 28, 1878, the Academy has received notice of the deaths of twelve members, as follows: six Fellows, Jacob Bigelow, Caleb Cushing, Silas Durkee, J. B. S. Jackson, John Clarke Lee, John M. Merrick, and B. F. Thomas; three Associate Fellows, W. C. Bryant, S. T. Olney, and George B. Wood; three foreign Honorary Members, Dove, Ritschl, and Rokitanski.

FELLOWS.

JACOB BIGELOW.

IT is greatly to be regretted that the subject of the following brief notice had not just enough of pardonable egotism and serviceable vanity to induce him to leave some record of himself in the shape of an autobiography. His birth dated from the year in which the Constitution of the United States was adopted. He lived into the last decade of the century which is reckoned from that event. For sixty-seven years he was a member of this Academy, and from 1847 to 1863 he was its President. Sagacious, observant, conversant with men, an intelligent student of public affairs, a thoroughly capable man of business, fond of social intercourse, eminent in more than one branch of science, one of the best scholars the classical training of his time had to show for itself, one of the earliest cultivators of the fine arts among us, always active in his laborious profession, yet always with time to spare for other and varied duties, a record of his life during the busy threescore years which would leave an ample margin for the period of immaturity and that of decline — a record such as he would have made — would have been a precious bequest to posterity. Of this crowded life I can offer but a few scanty hints and memories.

Jacob Bigelow was born in Sudbury, Massachusetts, February 27, 1787. His father, the Rev. Jacob Bigelow, who graduated at Harvard College in 1766, was minister of Sudbury, dividing his time between the

duties of his country parish and the cultivation of a farm of thirty or forty acres. His mother, a woman of superior sense and cultivation, was the daughter of Gershom Flagg, of Boston.

His boyhood was spent in attending a country school during five or six months of the year, and the labors and amusements of a country life, work on the farm, the study of natural objects, and the exercise of his constructive ingenuity in various mechanical contrivances. In the mean time, he conceived a strong desire of obtaining a collegiate education; and, though his father would have repressed his somewhat precocious ambition of mastering the learned languages, he obtained a Latin grammar, and in the woods and other solitary places found means to become acquainted with declensions and conjugations.

At thirteen years of age, he was sent from home to "fit for college" under the tuition of the Rev. Samuel Kendall, of Weston, a man "much renowned," as he says, "in his parish, as a breaker of unruly horses and refractory boys." He seems to have made the most of his time in College, so far as his relations with the various societies, religious, literary, and social, were concerned, besides which he took part in conducting a poetic periodical circulated in manuscript, his associates being his classmates Alexander H. Everett and Joseph G. Cogswell. He graduated in 1806. His "part" at Commencement was a poem; and on taking his second degree, three years afterward, he was offered the English oration for the Master's degree, but declined the honor.

Having chosen the practice of medicine as his profession, he began its study on leaving college, teaching school at the same time in Worcester. After a year, he returned to Boston, where he continued his studies with Dr. John Gorham, supporting himself in the mean time by discharging the duties of Assistant Teacher in the Latin School. Here he continued to cultivate that knowledge of the classics which has always been one of his remarkable accomplishments. In 1809, he was licensed as a practitioner, and in 1810, after attending a course of lectures at Philadelphia, he took his medical degree at the University of Pennsylvania.

His introduction to the public as an author was in the form of three successive Boylston Prize Essays, one of which, that on Burns, is distinguished by original experiments of a simple and convincing character. After this, he delivered the annual poem before the Phi Beta Kappa Society, and gave a course of botanical lectures in association with Professor Peck, which course was afterwards twice repeated by Dr. Bigelow alone.

In 1814, he published the "Florula Bostoniensis," a description of the native plants of Boston and its vicinity. This work, which was the principal consulting manual of local botanists, went through three editions, with various successive enlargements. Dr. Bigelow's reputation became widely extended, and genera of plants were named after him by English, French, and German botanists. In the following year, 1815, he was appointed Professor of Materia Medica and Botany in the Medical School of Harvard University; and in 1816 he received the additional appointment of Rumford Professor in the University.

In 1818, Dr. Bigelow began the publication of the "American Medical Botany," a work which extended to three volumes octavo, with plates, colored by a new process of his own invention. In 1820 was published the first edition of the Pharmacopœia of the United States, prepared by the delegates of a convention appointed from the various medical colleges and societies of the United States. A committee of five, Dr. Spalding of New York, Dr. Hewson of Philadelphia, Dr. Bigelow of Boston, Dr. Ives of New Haven, and Dr. De Butts of Baltimore, were charged with the publication. The part assigned to Dr. Bigelow was the list and nomenclature of the Materia Medica. In performing this task, he departed from the common usage of the British colleges, and in all possible cases employed a single name for each drug in place of the double or triple names they had always used, a plan which is still adhered to in our National Pharmacopœia. He followed up this labor by publishing his practical treatise long familiar to the profession under the name of "Bigelow's Sequel," a succinct, judicious, and perspicuous commentary on the characters, qualities, and uses of the remedies adopted by the national medical representatives.

In 1825, Dr. Bigelow gave the first impulse to a great movement which has made itself felt in its beneficent influences throughout the whole length and breadth of the country. His attention had been accidentally called to the gross abuses associated with the system of intramural burials. In consequence of this, he invited about a dozen gentlemen to meet at his house in Summer Street, to consider the expediency of instituting an extra-urban, ornamental cemetery in the neighborhood of Boston. This meeting, after long delays and discussions, found the fulfilment of its suggestions in the creation of the cemetery of "Mount Auburn," consecrated in 1831, the first institution of the kind in the United States, and the pattern after which have been modelled a great number of similar institutions, which have been grow-

ing up, during the last thirty or forty years, in the neighborhood of our chief cities and towns. It is hard to overrate the importance of this great innovation on the time-honored custom which was fast becoming a nuisance to the public health and an offence to the common feelings of humanity. The close-packed tombs, liable to be used by unscrupulous sextons as lodging-houses for any homeless dead whose means would purchase a temporary resting-place; the graves where one body was piled on another until only a few inches of soil covered the last-comer's coffin-lid, — gave place to the peaceful and secure rural retreat where the dead could repose undisturbed and the living could resort with pleasure. Not only was the project of the Mount Auburn Cemetery due to Dr. Bigelow, but he furnished the designs for the fence and gateway, the chapel and the tower, and for more than twenty years officiated as President of the Corporation.

In 1830, Dr. Bigelow published the "Elements of Technology," a treatise on the application of the sciences to the useful arts, taken chiefly from the lectures delivered by him as Rumford Professor at Cambridge. This most convenient and valuable manual has since been reprinted (1840) with additions, in two volumes, under the title "The Useful Arts."

In 1832, Dr. Bigelow was commissioned by the City of Boston, with the late Dr. John Ware and Dr. Joshua B. Flint, to visit New York to observe and report on the Asiatic cholera, then prevailing in that city. So great was the fear of contagion at the time, that the Committee, returning in one of the Sound steamers, were stopped a mile below Providence by the health officers, and forbidden to come on shore. Landing at Seekonk, they at length, after waiting a whole day, made their way to Boston in stage-coaches.

In 1835, Dr. Bigelow delivered, as the annual address before the Massachusetts Medical Society, his well-known discourse on "Self-limited Diseases." This remarkable essay has probably had more influence on medical practice in America than any similar brief treatise, we might say than any work, ever published in this country. Its suggestions were scattered abroad at the exact fertilizing moment when public opinion was matured enough for their reception. The essay of Louis on blood-letting in pneumonia had shaken the belief of many in the "strangling" of disease by heroic remedies. The French expectant practice had been watched in the hospitals of Paris by multitudes of students, who had become accustomed to see patient waiting and mild palliatives take the place of the perturbing measures familiar to English and American usage. Dr. Bigelow's discourse

summed up the question between nature and medical art so fairly and so clearly, that from that day forward the empirical habit of interference, for the sake of interfering, with the course of a self-evolving and self-terminating disease may be said to have declined.

This essay was republished in a volume, with sixteen other papers, in the year 1854. Every one of these papers will be found marked by the characteristic excellences of the writer, from the Experiments on the Effects of Different Methods of Treating Burns, the Boylston Prize Dissertation before referred to, to the Address delivered before this Academy at the opening of their course of Lectures in 1852. Another little volume, "Expositions of Rational Medicine," published in 1858, illustrated the doctrine of the Discourse on Self-limited Diseases in a fable called "The Paradise of Doctors," followed by a short essay and an appendix, containing a reprint of a part of an article by Sir John Forbes in the British Foreign Medical Review. Dr. Bigelow always selected the right subject; he always knew just what iron was lying white on the anvil. He had the art in which the telegraph has been giving the new generation lessons, — that of using just as many words as were needed to convey his meaning clearly, and no more, except that his wit or his learning would betray itself now and then by a lively illustration or an apposite quotation. He always went straight for the vital point in the subject he was handling: it was he who in our debates before societies waited until others had teased the subject under discussion until it was wearied and bewildered, and then gave it the *coup de grâce.* His style was that of a scholar who wears his robes of learning with such ease that no common-sense movement of his intelligence is hindered or made awkward by them. The President of our Historical Society, Mr. Winthrop, always felicitous in his characterizations, has coupled the name of Dr. Bigelow with that of "the great Bostonian," Benjamin Franklin. No comparison could be happier. Franklin was not college-bred, like our contemporary; but he had a literary turn, and composed ballads in his early youth, and used language as simple and lucid as any man who ever wrote English. Both were good-natured and good-tempered; both had a charming vein of pleasantry, which often showed itself in genuine wit and humor; both were abounding in mechanical ingenuity; both had a shrewd eye for the practical, and knew well how to handle their resources so as to make them tell with the best effect; both questioned the universe in a smiling, half-philosophical, half-practical sort of way, having, as one might say, a constitutional trust that things would come out right in the end; both, it may be suspected, carried a good many unsolved

problems quietly resting a little out of sight, — certainly not aggressively thrust forward, — in a receptacle like that in which Time puts alms for oblivion. I should form this opinion with regard to Dr. Bigelow, chiefly from the habit of his mind, which was that of exploring Thomas rather than of visionary Paul; for I never knew him wanting in reverence, and I have known him to manifest impatience at what he thought was a want of it.

The last great movement in which Dr. Bigelow took an active part was that in favor of a change in the educational system by which the classical languages should cease to be the exclusive or chief tests of a liberal training. Professor W. P. Atkinson had recently called attention to the state of education, especially as it regarded the classics and scientific studies in the great schools of England. Dr. Bigelow referred to this as a convincing exposition of the state of education in those institutions, and, following his usual direct method of proceeding, made a practical application of the facts there given, illustrated with a good sense and epigrammatic force all his own, to the condition of things among ourselves. His two papers bearing on this subject, "On the Limits of Education" (1865), and "On Classical and Utilitarian Studies" (1866), were published with other essays in a volume entitled "Modern Inquiries" (1867).

After a record like this, it seems almost trivial to refer to the literary diversions in which from time to time, generally without attaching his name to them, he was in the habit of indulging. I think it probable that he wrote more frequently in the papers than any of his friends were aware; for I remember more than one article of his, the authorship of which was not generally known. His *jeux d'esprit* could hardly help betraying themselves, in some instances at least. One of the most famous was the poem written on the occasion of the transplantation of the gingko-tree from the garden of Mr. Gardiner Green to Boston Common. Another of his happiest efforts was the Latin song written for the Harvard Centennial in 1836. It deserves every epithet Cicero bestowed on the oration which he called *concinnam, distinctam, ornatam, festivam.* The little volume of playful parodies called "Eolopoesis" has always been attributed to him, without having its authorship disputed. These productions were the mere overflow of a mind full of wit as well as wisdom.

Dr. Bigelow has done more than adorn all that he has touched: he has illuminated and enriched, as well as embellished, a range of subjects so wide that it becomes a wonder how he could embrace them all. Few citizens of the republic, certainly no member of the medical

profession, can be said to have identified himself with so many and such permanent contributions to the public welfare. He was fortunate in living to see the science for which he labored in his youth flourishing in the hands of able successors who have given their lives to it, to behold the whole land beautified with those rural cemeteries of which he furnished the American model in Mount Auburn, to witness the establishment of a more philosophical and safer medical practice as a consequence of his outspoken appeal to nature and common sense, and to enjoy the prospect of a more liberal administration in our colleges and universities as a reward for his manly plea in behalf of the more practical branches of knowledge.

It would be hard to find any one better fitted to wrestle with the years that close the labors of a long protracted life than was the strong and firm-souled man whose career through its more active period we have been glancing over. His constitution was robust, his habits were more than temperate, his mind always active, but working easily in every kind of service to which he called it. And there never was a man who accepted the combat with his growing infirmities in a more courageous and cheerful spirit. In the year 1870, at the age of eighty-three, he was still in the possession of much bodily vigor and mental vitality. He took a fancy to pay a visit to the other side of the continent, and carried it out with all the spirit of his younger days. On his return, he wrote a very lively and pleasant little poem, recalling the vivacity of the lines to the gingko-tree and others of his earlier efforts. In the same year, he wrote, and read at a meeting of persons interested, the Essay on Education before referred to. But the time was near at hand for all his active labors to cease.

With the exception of some deafness on one side and the fracture of an arm by a fall, I do not recollect his ever suffering from any infirmity that made itself manifest until the last decade of his life. A dimness of sight, which came on very gradually, was the first sign which made itself obvious. It was found after a time that this dimness was owing to the formation of cataracts in both eyes. It was quite wonderful to see the way in which he accepted a fact so threatening to the happiness of his remaining years. He seemed to look upon himself with curiosity as the subject of an experiment by Nature. What he had to do was to train another sense to perform the task of the one which was failing. His description of the way in which he taught his hands to work without the guidance of sight was given with so much apparent delight that one might have thought he enjoyed more in perfecting the groping organs of tact than he suffered in losing the swift illimitable potency of vision.

Books at length could no longer serve his failing sight; still he recognized the faces of those around him, and was gladdened by the cheerful light of morning. But the curtains were drawn closer and closer, until at last he could distinguish his friends only by their voices. And, as the years moved onward, each took something from the gradually yielding organization. A loss of power in the lower limbs rendered him helpless, and soon confined him wholly to his bed. Who could have wondered if the burden of his lamentation had borrowed the words which Milton puts in the mouth of the blind captive, — the strong man of Israel?

> "Scarce half I seem to live, dead more than half.
> O dark, dark, dark, amid the blaze of noon,
> Irrecoverably dark, total eclipse
> Without all hope of day!"

Not such were the words, not such was the spirit in which this once strong man, now blind and bound in chains heavier than any captive wears, spoke with his visitors. He greeted them with the same cheerful cordiality with which he had received them in health. His mind showed much of its old vivacity. He was often intensely interested in conversation; and his sense of the ridiculous, which in him was the sign of exuberant life in a happy temperament and a quick and penetrating intelligence, had lost nothing of its acuteness at a time when his bodily infirmities had become such as to render him entirely helpless.

Dr. Bigelow's life at this time was a kind of intellectual hibernation. He was living on the stores of a long and active period of mental labor and acquisition. He called on his memory to restore its buried treasures, and it obeyed him with singular docility. Passages from the classic authors, from his favorite English poets, Byron especially, retraced themselves at his bidding, with an accuracy that was surprising. Not long before the closing stage of mental decline, I remember talking with him about his reminiscences of the physicians of an earlier generation. He always had a keen eye for every kind of pretension, and could let the nonsense out of a tumid celebrity with an epigrammatic phrase or a characteristic anecdote in a way which would have made him terrible, had he not been very good-natured and altogether too knowing to give babblers and simpletons a chance to quarrel with him. He never said a malicious thing in my hearing; but when there was nothing to restrain him, he made very short work with overrated celebrities, and the "most magnanimous mouse" that had been pronounced a lion subsided into his proper and harmless dimensions, under his handling, with wonderful celerity. There never was a kinder sat-

irist than he: not only did he refrain from the use of poisoned shafts, but he kept his arrows so carefully in their quiver that only a friend, who was privileged to feel their points now and then, knew how sharp they were, and how dangerous they might be. His parodies were ingenious, with no venomous stinging about them. Consequently he made no enemies. He kept his wit perfectly in hand, and never let it betray him into personalities, — at least after his college days, when he indulged in an *excursus* or two which showed what a formidable weapon his ridicule could be, if he chose to wield it.

I was in the habit of visiting Dr. Bigelow from time to time long after the period at which the strength of our days was said of old to be labor and sorrow. But my visits were cheerful, except for the sight of the once strong man now blind and helpless in the bed from which he was never to rise. He smiled a welcome as always, laughed on occasion almost as heartily as ever, spoke of his remarkable freedom from all pain and discomfort, and wore on his features the look of serene repose.

I will close my sketch by repeating a few words from my remarks at a meeting of the Massachusetts Historical Society, where I was called to speak informally, at one of their meetings, of their late associate: —

The faculties still declined, gently, gradually, but surely, the mysterious presence of life still revealing itself in the simpler and humbler forms which belong to its infancy and its worn-out stage of decay. But the intellect still asserted itself in certain limited portions of the thinking centre. When life had become little more than mere existence, and persons were hardly if at all recognized, he would finish a quotation from some favorite author, if a few words or a line of verse were mentioned in his hearing. He would even go back, if he had made a mistake, and correct it with automatic accuracy. This mechanical action of the memory could not fail to recall the way in which the phonograph repeats a few connected words of the last sentence which has been dictated to it before it begins reciting its new lesson. Could he have watched the gradual extinction of his faculties, as the dying Haller felt the artery at his own wrist, as he himself had watched the progress of his gradual loss of sight, he would have studied

"with eye serene
The very pulse of the machine,"

and noted the phenomena of mental decadence as quietly as in his earlier years he watched the disrobing of the flowers which were

dropping their petals. But Nature drugs the victim of her last experiment, and her anodyne saves him from the spectacle of his own transformation from the strong man up to whom others looked, and on whom they leaned, to the helpless invalid whose weakness only pitying eyes behold, and whose little remnant of life is only prolonged by the hourly ministry of gentle and loving hands.

We look back through these last years of infirmity, and see the quick-witted student, the hard-working young physician, the enthusiastic botanist, the accomplished scholar, the eminent practitioner, the sententious, finished, and effective writer; the reformer, who, in a lecture of one hour, inaugurated such a change of medical opinion and practice as no other essay or work by an American author ever did in this country; the social innovator, who, by his origination of rural cemeteries, has done more for the beauty and health of our whole land than perhaps any other one man has ever effected; the philosopher, who in health was the most cheerful as well as one of the most unwearied of workers, and who, when the evil days came upon him, in which he might have been excused for saying, "There is no pleasure in them," bore every burden of infirmity which was laid upon him with more than resignation, — with an unfaltering equanimity which makes his years of weakness as memorable as those of his strength and activity.

HON. CALEB CUSHING, LL.D.

The Hon. Caleb Cushing, LL.D., died at his residence, in Newburyport, Massachusetts, on the 2d of January last. Born on the 17th of January, 1800, he was on the verge of completing his seventy-ninth year. He was graduated at Harvard University, as the third scholar in rank, in the distinguished class of 1817, and remained at the University for two years as Tutor in Mathematics and Natural Philosophy. He soon afterwards entered on the practice of the law, for which he had studied at Cambridge in the mean time. From this period, his long life was filled out, almost to the very end, with professional or public labors, and no man of his time has left a record of more indefatigable industry. He was the Representative of Newburyport in the Legislature of Massachusetts in 1825, and was repeatedly in the service of the State, either as Representative or Senator, in subsequent years. In 1835 he was elected to the House of Representatives of the United States, and remained a member of that body, by successive elections in the Essex District, until 1843. He was then

made Commissioner to China, and in that capacity negotiated the first Treaty between the United States and the "Celestial Empire." Soon after his return home, and when he had again become a Representative in the State Legislature, the war with Mexico gave him an opportunity to gratify his early disposition for military service. He raised a regiment of volunteers, mainly at his own expense, and conducted it as colonel to the Rio Grande, where he was commissioned a Brigadier-General. In 1850, he was Mayor of Newburyport, then recently incorporated as a City. In 1852, he was appointed one of the Associate Judges of the Supreme Court of Massachusetts; and, after a single year of faithful service in that office, he was taken into the Cabinet of President Pierce, as Attorney-General of the United States, and held that distinguished office for four years. The printed volume of his official opinions during that term bears signal testimony to his ability, research, and untiring labor. In 1866, he was appointed one of three commissioners to revise and codify the laws of the United States. Meantime, during the five previous years, he had spent much of his time at Washington, and had rendered important aid to more than one of the Departments in the difficult questions arising out of the Civil War. His last conspicuous service was at Geneva, as one of the counsel of the United States at the great International Arbitration of "the Alabama Claims," where he displayed his accomplishments as a linguist by making his argument in the French language. Few Americans have exhibited greater versatility, or greater ability, in so striking a variety of pursuits and services. As a scholar, as a lawyer, as a statesman, as a diplomatist, he has left a mark on our State and National records which cannot be obliterated. As a speaker, a thinker, and a writer, too, he has secured for himself no common place among the literary men of his period. He was elected Fellow of this Academy Nov. 12, 1823.

SILAS DURKEE, M.D.

Silas Durkee, M.D., was born in Hanover, N. H., Nov. 22, 1798, and died in Boston July 17, 1878, in his eightieth year. He graduated in Arts at Dartmouth College, in 1822, and in Medicine in 1826. He practised his profession in Portsmouth till 1841, when he removed to Boston, where he became a prominent practitioner, and accumulated quite a property for a medical man. He was a frequent contributor to professional journals; and published two octavo volumes on dermatology and allied diseases. These works, one of which

obtained a Boylston Prize, were received with much favor, and went through several editions. His leisure he devoted to the study of marine botany and entomology. In 1854, he was elected a Fellow of this Academy. In 1859, he was chosen an Honorary Member of the State Society of New York; and in 1860, a Corresponding Member of the Natural History Society at Montreal. He was for a time a Consulting Physician of the City of Boston; and continued on the Consulting Board of Physicians and Surgeons of the Boston City Hospital from 1864 to the time of his death.

Dr. Durkee was a warm-hearted and true friend, a faithful physician, an ardent promoter of science, and a Christian gentleman. His death is lamented by a large circle of friends, in and out of the profession.

JOHN BARNARD SWETT JACKSON.

John Barnard Swett Jackson was the fourth and last child of Captain Henry and Hannah (Swett) Jackson. He was born in Sudbury Street, Boston, June 5, 1806, and was named after his mother's brother, Dr. John Barnard Swett, a much respected physician of Newburyport.

He was but six months old when his father died. His uncles, the late Hon. Charles Jackson and Dr. James Jackson, became his natural guardians, and treated him like one of their own children. After going to several schools, where he proved himself diligent and exemplary in conduct, he went at the age of thirteen to a school kept by Mr. Hall, where he was fitted for college. At fifteen, he entered Harvard College. His classmate, Dr. Samuel Kirkland Lothrop, bears witness to his being eminently faithful, aiming ever to do in the very best and most thorough way that he could whatever work or duty he had to perform. No temptation, he adds, would have made him hesitate or swerve, or do or say any thing that was not honest and true. "He was true, open, frank, concealing nothing, because there was nothing he wished or that needed to be concealed. He was modest, unassuming, as far from all arrogance and pretension as he was from envy, jealousy, and a spirit of rivalry." He maintained a respectable if not an eminent rank, and received appointments to two "parts" during his college career.

He graduated in 1825, and immediately began his medical studies under the instruction of Dr. James Jackson and others associated with him. In 1827, he was chosen house apothecary for one year at the

Massachusetts General Hospital, — "being found better fitted than any other applicant." In 1829, he took his medical degree and went to Europe to continue his studies. In Paris, he attended more to surgery than to medicine, following the visits of Dupuytren, Roux, and Lisfranc. In London, he attended the visits at Guy's Hospital and the Lectures of Mr. Lawrence; in the evening Dr. Blundell, at 8 A. M., then the lectures of Dr. Turner on Chemistry at the London Hospital, at least three miles off, — back at 12 o'clock to Guy's Hospital. Besides these well-known names, I find that of Mr., afterwards Sir Charles, Bell, and many others. "Sir Astley Cooper," he says, "was very courteous to me, — spent much time with me in his museum, and treated me for a dissecting wound on my right hand." "I saw much of Drs. Bright, Addison, and Hodgkin, — spent much time at hospitals and autopsies." After passing three months in Edinburgh, attending Mr. Syme's Hospital and the Port Hopetown Dispensary, he sailed for home, as physician to the ship in which he came, in June, 1831.

He must have been, I should think, considering his training at home and abroad, and the indefatigable industry with which he availed himself of all his advantages, the best educated young physician who had ever established himself in Boston. But in medicine, as in politics, nothing succeeds (in a certain sense) but success. Dr. Jackson was too much devoted to the acquisition of knowledge to expend much thought on acquiring a large circle of patients. He can have had little lucrative practice, when in 1835 he accepted the position of house physician and surgeon at the Massachusetts General Hospital. During one year of the four while he held this post, he received a small salary, but the duties of these two offices, which were separated when he gave them up, must have occupied the greater portion of his time, and they must have paid him with only partial support, but abundant sources of instruction.

In the year 1839, he was chosen one of the physicians in full standing of the Hospital. He discharged the duties of this office faithfully for twenty-five years, and after his resignation was chosen one of the consulting physicians of the Hospital, so that for forty-four continuous years he was connected with the Institution.

A large part of the most valuable work of Dr. Jackson's life was done as a member of the Boston Society for Medical Improvement. This Society, which was organized in the year 1828, has flourished to the present time. The meetings have been faithfully attended by some of our busiest practitioners, and from its records great numbers of interesting cases have been given to the public. Of this Society, Dr. Jack-

son was the centre and the life, in a far truer sense than Louis XIV. was the throne. Never absent; almost invariably contributing some new fact, some valuable specimen; full of enthusiasm in his description of those fractions of diseased organs, the changes of which he studied with the greatest nicety before he attempted to display and describe them; saving carefully whatever was worth saving; not wasting himself in hoarding duplicates of common lesions which every week of a city's practice can furnish, — the Society soon found that under the hands of one man, unpaid except with the empty title of Curator, a choice Museum was growing month by month and year after year into completeness. For more than forty years Dr. Jackson was Curator of this Museum, now known as the Jackson Cabinet, and by a vote of the Society to be transferred to the Medical Department of Harvard University whenever a new building shall be ready to give it safe and fitting accommodation. For a great many years it has been a central point of attraction to all our medical visitors. Dr. Jackson never appeared to greater advantage than in going through this admirable collection with an intelligent professional brother from some other town or country. He knew his specimens as a father knows his children. He was not one of those collectors who gratify their acquisitiveness in picking up every thing they can which others want, and their vanity by showing what they hope nobody else possesses. It was what a preparation taught or illustrated which rendered it valuable in his eyes. The value of the two collections which he in large measure built up, and thoroughly arranged and described, consisted very much in the histories of the cases of which they were the material records, and which he took the greatest pains to have and to set down in his catalogues. Under many circumstances, he was rather slow and labored in speech than happy as an orator, but, with one of his choice specimens in his hand and an interested listener, he became warmed and inspired with an eloquence all his own. This characteristic never left him. I remember when he came back not many months ago from Washington, bringing with him photographs of certain crania he had there seen and studied, with what boy-like ardor he, now past the period at which the fiery and impassioned king of Israel "gat no heat," expatiated on the disappearance of the nasal bones, their place being supplied by the meeting of the ascending portions of the superior maxillary. This was only one instance of his inextinguishable youthfulness of excitability. In 1847, he published a descriptive catalogue of the Museum of the Society for Medical Improvement, in a well-filled octavo volume of three hundred and fifty pages. It was of this

work that a distinguished Philadelphia Professor spoke, as the most important contribution yet made in America to pathological anatomy.

In 1847, he was appointed to the Chair of Pathological Anatomy in the Medical School of Harvard University, a new professorship created and endowed by the liberality of the late Dr. George Cheyne Shattuck, with express reference to its being conferred upon Dr. Jackson. With this office was joined that of Curator of the Warren Anatomical Museum. This collection, which had been formed by the late Dr. John Collins Warren, in the midst of the incessant cares and labors of a great practice, contained much that was of value, but absolutely required the most complete revision and reorganization. To this work Dr. Jackson devoted himself with his usual energy. Every specimen was carefully examined, its proper preservation attended to, its fitting display obtained by readjustment, its history sought out,— in short, the same loving care bestowed upon it as had been lavished on the specimens which belonged to the collection he had himself brought together and labored over with paternal devotion. He retained the office of Curator until the time of his death, and it was on returning from his work-room in the Medical College that he complained of the first symptoms of the disease which in a week's time brought his labors with his life to a close. For the last few years he had not lectured, but his time was still given without stint to caring for and building up the Warren Museum with which he had incorporated so much of his time and toil.

In addition to the two important volumes which I have mentioned, Dr. Jackson published a very large number of separate communications to the Medical Journals, and left behind him a great mass of manuscripts. His recorded cases are two thousand and sixty-two in number. The first autopsy entry was in 1830, the last was in 1869. These records fill five large quartos of nine hundred pages each, and seven small quartos of five hundred pages each, all in his own small and compact handwriting. These he had reviewed and tabulated, with the intention of making them more valuable and probably of publishing them. Those who know his fidelity, his patience, his keenness of observation, his scrupulous accuracy, will feel assured that, if this labor is completed by those who come after him, he will need no other monument.

He diversified his heavier work with pleasant excursions into the field of comparative anatomy. He dissected an elephant, a spermaceti whale, a rhinoceros, a male and female dromedary, a horse, and very numerous lesser animals, often detecting some point which others

had overlooked, and showing it with a delight which illuminated every feature of his refined and delicate countenance.

His vacations were seasons of work, but work was his chief pleasure. In 1851, he spent six months in Europe, visiting all the principal museums. He has left a large volume of notes of the rarest and most interesting specimens he saw, to the number of seventeen hundred and ninety-two. These he arranged and catalogued under suitable heads in 1858.

He went to Barbadoes in the spring of 1867, stayed only a few days, and after his return wrote an account of the diseases of the island. He had several intervals of this kind of idleness, which most men would have called industry. In January, he spent several weeks in Washington, and it was at that time that he studied the Esquimaux skulls, and made, as he thought, some original observations upon them.

In his last voyage to Europe, in 1874, he had a remarkable escape from a disaster which was every thing but shipwreck, the vessel having been abandoned, and afterwards picked up and carried into port. I do not remember his ever speaking of it; but, from the account his son who was with him gave, the immediate risk must have been very great, and the danger, as well as the suffering from exposure and hunger, enough to try the stoutest at the lustiest period of life. A slight exposure, if indeed such were the active cause of his disease, brought on the consequences which cold and wet, and the smothering forecastle of the vessel which rescued the passengers drifting in their open boat, had failed to produce.

On Monday afternoon and evening, December 30th, he was at work at the College. He came home, felt very weary by half past eight, lay down on his bed, and never after that voluntarily lifted his head from his pillow, and quietly passed away on the 6th of January, 1879, the Monday following that when he was taken with the first symptoms of his disease, which was pneumonia.

This sketch may be concluded with some extracts from a notice of Dr. Jackson furnished by the writer to the Boston Medical and Surgical Journal for January 9, 1879: —

The death of Dr. Jackson comes upon us as a loss we had little contemplated and for which we were quite unprepared. Age had not left him unchanged, but it had never subdued his elastic and almost youthful nature. A sudden and brief illness, attended with less of suffering than that which we are too often called to witness, ended in a few hours of unconsciousness, followed by a quiet release.

No man has ever died among us who has been more universally loved and respected, or whose loss has been more felt than his will be by the members of the profession to which he belonged. He was less widely known to the community at large than many others, but it would be safe to say that no one ever heard his name mentioned but in tones of kindly regard, or his character referred to except as that of a man without guile, true as truth, pure as purity, honest as Nature herself, whose works he studied. It may sound like extravagant language to claim so much for him, but he was quite exceptional in the singular childlike simplicity and transparency of his character, and in using the expressions here applied to him it is only among those who did not know him that such words need fear questioning comment.

It was not in medical practice that Dr. Jackson was chiefly known among us. He was not in all respects fitted for the every-day work which belongs to that laborious calling. He was perhaps too sensitive, and, if such a word may be ventured, too scrupulous, to work quietly and easily to himself, which is one great condition of success. A great physician must have something of the great general about him, and more than one great general has left it on record that he could get a good nap on the battle-field in the interval of its decisive moments. The singular delicacy of Dr. Jackson's nature stood in the way of his success in the rough out-door world where men are necessarily jostled together in competition. With his vast knowledge of disease, it might have seemed that he would be wanted everywhere in consultation. Perhaps he knew too much, — knew the tricks of Nature which baffle the most skilful diagnosticians too well to speak with that positiveness which is often decisive, in virtue of its personal emphasis, in cases where doubts are plenty and convictions feeble; where in the words of the great old master, "The moment is pressing, experiment dangerous, judgment difficult."

Nor was it in the routine of medical practice that Dr. Jackson won that great reputation which reaches all over the land, and beyond it, wherever pathological science is cultivated. He studied disease in its effects upon the organs. There was a long series of years during which the ruined or injured vital machinery of our fellow-citizens, the cause of whose death was asked by those interested, was almost certain to pass under his thorough and careful inspection. The results he found in each case he minutely recorded. The history of the disease he took the greatest pains to learn. What Morgagni did for Valsalva he did for the whole medical profession of our city. In this way, he accumulated a great mass of original materials, fresh transcripts from

nature, which as far as they professed to go would be more likely to gain than lose by comparison with the famous works of an earlier day, the *Sepulcretum* of Bonetus, the great treatise *De Sedibus et Causis Morborum*, or the *Clinique Médicale* of Andral.

"As far as they professed to go." There is no propriety in comparing pathological anatomy as Dr. Jackson studied it with the pathological histology of a later epoch. He was not a microscropist. The telescope of the infinitesimal universe had not perfected its eyesight until long after he had become an adept in studying the larger aspects of diseased structure. What he knew he knew thoroughly, but he never pretended to have the slightest knowledge beyond what his honest naked eyes could teach him. He was not ashamed of their nakedness: in fact, it was next to impossible to coax him to look through a microscope. He would turn away with, "I know nothing about it," in a tone that implied he did not want to have any thing to do with it. But these same honest eyes of his were very keen ones, and saw things with about as little of chromatic or other aberration as any that have opened to our daylight. His look penetrated like an exploring needle, and many a tympanitic fancy of careless observers has collapsed under its searching scrutiny.

This is not the place to do more than allude to the record he has left of himself in medical literature. For half a century he has been at work among us; and the inventory of his finished labors, were it made out in full, would astonish many of those who have seen him only when he was busied with some of those smaller tasks in which he was punctilious to an extent that now and then provoked a good-natured smile. He had the true genius of a curator, and was never tired of working at his specimens, to get them into the best condition and show them off to the best advantage.

As a lecturer, Dr. Jackson was exact rather than fluent or copious in expression, but his knowledge was so genuine and so thoroughly his own that it commanded the closest attention and the greatest respect. For the last few years he has not lectured, but confined himself to his duties as curator. Never was there a more enthusiastic devotee to that particular kind of work. He was a picture of cheerful content in the midst of the fragmentary specimens of Nature's handiwork by which he was wont to be surrounded. No student in the first flush of his boyish enthusiasm was ever more full of excitement, more radiant with delight, than this man whom the record called old, but whom his unquenchable vitality preserved ever youthful and ever happy in illustrating some fact by a new preparation, or in

rendering presentable some dilapidated tenant of his immortalizing receptacles.

In many points, he resembled that model of all the finest qualities which belong to the student of science, Dr. Jeffries Wyman. In both the love of knowledge for its own sake was the divine gift which set them apart from the men of mixed motives, who have a conditional liking for truth among many other things. It is truly an inspiration, as much so as that of the poet, which renders students of nature like Wyman and Jackson restless under the stimulus of half knowledge, and keeps them wakeful until they have got at some secret which seems to hide itself from their search. Few, very few of our men of science pass so large a part of their lives in their laboratories. In both there was the same union of modesty of statement with confidence in the accuracy of what they alleged as the result of their own observation. Each knew the other's exactness and trustworthiness. Dr. Jackson often cited the keen observations of Dr. Wyman with the evident feeling that he was referring to a man whose eyes were as sharp as his own, — the highest compliment one observer can pay another. He would not have claimed the discursive range or the inventive ingenuity which so eminently belonged to the Cambridge biologist and comparative anatomist, whose large outlook took a wider field of knowledge for its province. But, differing in their special gifts, their noblest qualities were such as belonged equally to both. If such a title were known to the calendar as Saints of Science, both these faithful, sincere, modest, pure-minded students of nature would be numbered among them.

A new generation had grown up since Dr. Jackson had passed the middle term of life. The aspect of his chosen branch of knowledge had greatly changed since he stood forth as its oracle among us. But the whole profession knew what he had done for it; the older members had seen him building up the two museums of which he was the chief architect; the younger knew, in some measure at least, the breadth and depth of his long-continued labors. So when a few years since the proposal was made that he should be invited to sit for his portrait, it met with a response which showed that the profession which he had served so long and well could not wait to bear their testimony to the universal esteem and veneration in which he was held until that term should be reached when praise wastes itself unheard by those upon whom it is lavished. His quiet life will be long remembered in the truly monumental works it has left as his record.

Dr. Jackson married in 1853 Emily J., daughter of William T. Andrews, Esq. He leaves two sons: Henry, born October 25, 1858; and Robert Tracy, born July 13, 1861.

Many honors have been paid to his memory. His old friend and schoolmate, Rev. Dr. Chandler Robbins, the Rev. Dr. George E. Ellis, and his classmate, Rev. Dr. Lothrop, took part in the funeral services at the house or in the church, and all bore testimony in strong and impressive words to the beauty of his true and useful life. Many of the associations with which he was connected passed resolutions expressing their deep sense of his high qualities and the loss they had sustained.

JOHN CLARKE LEE.

John Clarke Lee was born in Boston, April 9, 1804, and died in Salem, November 19, 1877. Through his father he belonged to a family that has borne an honored name through nearly the whole period of New England history, and he also traced his descent to the Pickerings of Salem, — a name held in no less merited reverence. He belonged to the class of 1823 in Harvard University. After leaving college, he pursued for a short time the study of the law; but soon left it for commercial pursuits. At quite an early age he retired from business; but subsequently became the senior partner of the well-known banking-house of Lee, Higginson, & Co., of which he was a member from 1848 till 1862. From 1829 till his death he was a resident of Salem, in the enjoyment of an ample fortune, and for the greater part of the time in the possession of a leisure free from all imperative demands, yet never idle or useless. He was an early and active member of the Essex County Natural History Society, and continued his valued services to the Essex Institute, which absorbed and succeeded it. He was a Trustee and Director of various financial corporations, and for a few years held the office of Treasurer of the American Academy. He in general shunned municipal and political offices, for which he would often have been a preferred candidate, and the only place of this sort which he is known to have filled is that of Representative of Salem in the State Legislature for a single year.

Mr. Lee, without being distinguished as a specialist in any department, was a man of superior ability, active mind, and generous culture. His information on a large range of subjects was extensive and accurate. He was a lover of learning and science, and while we cannot name any original contributions of his own, his encouragement, effi-

cient aid, and warm appreciation were never wanting to those engaged in scientific investigation or in literary labor.

Mr. Lee was a man of sterling integrity, and of a high sense of honor. In private life, and to a large circle of kindred and friends, he was endeared by those traits of character which are the ornament and joy of home and of refined and cultivated society. His kind offices were never wanting where there was the need or the opportunity for them. It is hardly enough to say that he was unselfish. He probably would not have claimed this praise. But he had so large and comprehensive a self-love, that it could be satisfied only when he had contributed to the utmost of his ability to the happiness of those around him, of whatever age or condition. He was thus loved and honored in life, and for not a few his death seems an irreparable loss.

JOHN MUDGE MERRICK, S.B.

John Mudge Merrick, of Walpole, was the youngest son of the late Rev. John Mudge Merrick. He was born at the Swift Hotel, in West Sandwich, Cape Cod, Massachusetts, April 12, 1838, at which place his father was then settled over the Unitarian Society.

Shortly after the birth of his son, Mr. Merrick was called to the church at Walpole, where he was settled for many years.

In 1857 Mr. Merrick entered the chemical department of the Lawrence Scientific School, and he was graduated from there *summa cum laude* in 1859. After graduating he served for one year as assistant to Professor Horsford.

In 1862 he was appointed principal of the High School at Natick. He left this place to take a similar position at Canton, in the spring of 1864. Leaving Canton in 1865 he filled the position of Submaster in the New Bedford High School until the summer of 1867. During his vacations he spent his time in chemical work, and on leaving New Bedford he accepted the position of Superintendent of the Boston Diatite Company. In 1868 he commenced his active professional life as an analytical and consulting chemist in the city of Boston, and from that time until within a few days of his early death he was steadily employed at commercial chemistry.

During this time he was a constant contributor to the chemical journals, both at home and abroad. He was also one of the contributors to Johnson's Cyclopedia. In 1874 he was elected Professor of Chemistry in the Massachusetts College of Pharmacy.

Mr. Merrick's published contributions to chemistry have been in the form of short notes on working processes, rather than the results of any extended investigations. His extended investigations, the most prominent of which are on the nature of aniline black, on nickel-plating, and on bronzing articles of iron by coating them with linseed-oil and then subjecting them to a high temperature, have never been published, except in the records of the United States Courts. It was largely through his exertions that the optical method of testing the value of sugar has been introduced into commercial use in this city.

Besides his contributions to chemistry, he wrote many articles for the daily papers on matters of passing interest.

He was an active member of the Massachusetts Horticultural Society, and wrote and published a valuable essay on the cultivation of the strawberry. He also made a number of experiments on the production of wine from our common American grapes.

In 1875 he was elected a member of the American Pharmaceutical Association.

In 1874 he published, under the title of "Nugæ Inutiles," a collection of translations into Latin of many of the popular songs of the day.

Quiet and reticent in his manners, few were admitted to his intimate friendship, and it was only after long acquaintance that his worth was appreciated. Ambitious to do thoroughly good scientific work, he was hampered by the necessity of struggling for a living, and he had just commenced to see his way clear before him, when a promising career was cut short by his sudden death. He died at Walpole on the 25th day of February, 1879, of pneumonia, after a short illness, having been previously worn out by watching at the bedside of one of his children.

He was married in August, 1863, to Fannie, daughter of Smith Gray, of Walpole, who, with three children, survives him. He was the last surviving member of his immediate family, an only brother, his father, and his mother all having died within a few years.

BENJAMIN FRANKLIN THOMAS.

Benjamin Franklin Thomas was born in Boston, on Feb. 12, 1813, and, entering Brown University at the age of thirteen, graduated there in 1830. He studied his profession at the Law School of Harvard College, remaining there until 1832. Choosing Worcester as his residence, he was long distinguished as a member of the bar of that county, and held various local offices of honor and trust. In 1842 he

was a Representative from Worcester in the Legislature of the State, and from 1844 to 1848 was Judge of Probate for the county of Worcester.

In 1853 he was appointed a Justice of the Supreme Judicial Court of Massachusetts. He held this office for six years with distinction, and then resigned it, and, coming to reside in the neighborhood of Boston, began, as a member of the bar in that city, a long, honorable, and profitable career, which ended only with his death.

During this period he was for one term, from 1861 to 1863, a member of the national House of Representatives. In 1868 he was nominated by the Governor to the office of Chief Justice of the Supreme Judicial Court, to succeed Judge Bigelow; but a strong opposition, on political grounds, prevented his confirmation by the Council. He was also invited to a chair at the Law School of Harvard University; but while he did not accept this position, he consented to deliver lectures at this School, and also at that of the institution in Boston.

He died at his summer place, in Beverly, Mass., Sept. 27, 1878, at the age of sixty-five.

Judge Thomas was a man who would have been distinguished in any community. He is worthy of special commemoration upon the records of this Academy, as one of the few men of his profession who have combined devotion to their calling, and success in it, with the love and study of philosophy and literature. What is not so rare, but is rarer than it should be, they were combined also with the preservation of the ardent affections and the wholesome instincts and tastes of a generous nature.

ASSOCIATE FELLOWS.

WILLIAM CULLEN BRYANT.

The death of William Cullen Bryant removed from the list of our associate members one of the most eminent names in the annals of American literature. The familiar phrase of Tacitus has rarely been applied with more justice than it may be to Mr. Bryant: "Felix non vitæ tantum claritate, sed etiam opportunitate mortis." For he died, not only full of years and full of honors, but before age had wasted his faculties or diminished his powers of service. He had lived long enough to enjoy his own fame, and to be assured that his name would

be inscribed on the roll of the worthies of the nation. He had seen his country grow from comparative feebleness to a great power, and he had had a share, not only in influencing its political tendencies, but in determining its moral ideals. The last was his more important work. and it is as a poet who gave appropriate, elevated, and refined expression to the moral sentiment of the community that he will be chiefly remembered. His verse bears the stamp of New England. It is the outcome of the grave piety, the sober joys, the reflective seriousness, of the elder mood of the country. In this sense it belongs rather to the past than to the present; but the truth and felicity with which they express common and natural feelings and emotions will secure to the most widely known of Mr. Bryant's productions a permanent place in the pages of the household book of American poetry.

It is not needful here to give even a summary of Mr. Bryant's biography. This work has been done well where it might be done more appropriately. For his intellectual activity displayed itself chiefly outside the fields cultivated by this Academy. It is required only of us to bear our testimony of honor to the memory of a poet and public servant, who, born in Massachusetts, has, at his death, been claimed by the nation for its own.

JOSEPH HENRY.*

JOSEPH HENRY, who was united with this Academy as an Associate Fellow on May 26, 1840, was born in Albany, N. Y., on December 17, 1799, and died in Washington, D. C., on May 13, 1878, in the plenitude of his years, his labors, and his honors. The child is always father to the man: but there was nothing in the childhood or youth of Henry to proclaim the advent of one whose life would be a blessing to mankind, and whose death would be felt as a nation's loss. Descended from Scotch ancestors, who had recently emigrated to this country, and losing his father at an early age, he passed a large part of his youth under the care of his maternal grandmother, at Galway, in Saratoga County. Here he attended the district school until he was ten years old. Then he was taken into a store, where he was treated kindly and allowed to be present at the afternoon session of the school. Obtaining access to the village library, at first by accident, afterwards by stealth, and finally by permission, he revelled in an ideal world of

* The death of Professor Henry, although reported last year, took place so near the time of the annual meeting, that this notice was necessarily deferred until the present Report.

fiction, and perhaps cultivated, unconsciously, that faculty of imagination which served him as the interpreter of Nature.

At the age of about fifteen Henry returned to Albany and entered a watchmaker's shop as an apprentice. Whatever knowledge of mechanism and delicacy of touch were thus acquired were not thrown away upon one destined to plan and handle the nice appliances of physical research. And yet his heart was not in the new occupation. The stage, before the scenes and behind the scenes; private theatricals; a club of amateurs of which he was president, and for which he wrote and acted tragedy and comedy, — absorbed his time and thoughts. All who have seen and admired the refined, intellectual face, and the erect, dignified form of the ripe philosopher, can easily imagine the success of the young aspirant for dramatic distinction when these charms of person and mind were decked in the beauty of youth: the self-possession, the repose, and the grace of this expounder of physical science alone remained to tell of his short-lived eccentricity. Those readers who allow the mythical apple to divide with Newton the glory of a great discovery will listen eagerly to the statement that the theatrical career of young Henry was suddenly arrested by his accidental encounter, during a brief illness, with Dr. Gregory's popular lectures. The literal truth of the story is not questioned; for Professor Henry himself believed it, and reverently cherished the precious volume to the last. Such, however, was the occasion, but not the cause, of his dedicating himself henceforth to science. Innumerable accidents of a similar kind happen to every one, but not with the same result. Man, especially such a man, is not the creation of any accident. The inspiration comes from within: it is the unbidden thought, and not the external events with which it is associated. Said a great divine, "If you say that man is the creature of circumstances, it must be with the understanding that the greatest and most effective of these circumstances is *the man himself.*"

Bidding farewell to the stage and his theatrical companions, Henry went seriously to work to complete his education; at first in an evening school, then with an itinerant pedagogue, and finally in the Albany Academy, where he was both pupil and teacher. Next he was private tutor in the family of the patroon, devoting his leisure to the study of mathematics, and subjects which would fit him for the medical profession. In 1826 he made, in connection with Amos Eaton, the survey for a road across the State of New York. In this work he displayed so much energy and ability that his friends hoped to find, or to create for him, a permanent position as engineer. But the State failed to

respond, and Henry returned to the Albany Academy as assistant teacher, and in 1828 as Professor of Mathematics.

Only a few years had elapsed since the science of electricity had taken a new departure under the name of electro-magnetism. Oersted, of Copenhagen, had kindled the flame, which passed rapidly from hand to hand among the scientific workers of Europe, until it culminated in the splendid generalization of Ampère. This western continent may have been tardy in welcoming the bright light in the east, but the response, when given, was not a fire, but a conflagration. Professor
Henry led in the new line of phys
enthusiasm which seven hours of daily
not extinguish or cool. The limits of
statement of his contributions to electı
principle which he deduced from his
over in silence. His distinction between
and between *quantity* and *intensity* ba
expressed), is all-important and of
experiment with electro-magnetism, in
room, and in the arts, is a success or a f
is obeyed or ignored. If this discovery
name with the telegraph especially, it
problem of the hour, — unsolved, and
It is not easy to draw the dividing line
coverer and the inventor, when one fol
the other. Professor Henry's contribu
large, and brilliant, and indispensable; b
alphabet was wanting; a sustaining bat
over, a man must appear with a capac
born of hope, with no original knowledg
tricity but with an easy absorption of t
by a happy combination of experimenta
years, might finally achieve a grand co
Professor Henry's additional conques
research, science will ever rejoice that h
the inviting prospect of riches and po
nounced the fruits of invention when
grasp; that he preferred to any short-liv
of shining for ever as a star in the
Cuvier, and Faraday.

Loyalty to the devotees of scientific research does not demand any disparagement of the usefulness or the genius of inventors. If the

former enlarge the area of human knowledge, the latter contribute to the civilization of the race. If there are individuals in one class who think only of their pecuniary success, the other class is not without examples of those who mean to achieve, even if they do not deserve, a high scientific reputation. It is not incumbent on every scientific man to think, with Cuvier, that he must abandon a discovery the moment it enters the market, — that its practical application is of no concern to him. No one certainly has a better right to the fruits of this application than the discoverer himself. Inventors may sometimes stumble on good fortune; but the rich prizes are comparatively few, and, on the average, they are dearly earned by years of severe thought and anxious waiting. No graveyard holds so many buried hopes as the Patent Office at Washington. Since the first introduction of the telegraph, discovery and invention have advanced, hand in hand, over continents and through the ocean, leaving the world in doubt which to admire the most, — the conceptions of pure science, or the exquisite mechanism in which they are embodied. If on one occasion this harmony was disturbed by the repudiation of an indebtedness which had often before been freely acknowledged, the ingratitude was rebuked by the indignant voice of science, and the just claims of Mr. Henry were established on an impregnable foundation.

It does not detract from the merit or the originality of Professor Henry's early discoveries that the same ground had been covered by Fechner, in a work published in 1831, and that both had been anticipated by Ohm's experimental and mathematical analysis of the galvanic circuit, which dates back to 1827. For Ohm's little book of that date, which now shines as a foreland light for the guidance of all who explore in that direction, was known only to a few in Germany, and was unknown in France, England, and America at a time when, if known, it might have illuminated Professor Henry's researches. At a later period, Pouillet published the results of his own experiments, without knowing that he himself had been anticipated by Ohm. The father of Ohm had intended his son for a locksmith; but, unlike Henry, he did not even begin his apprenticeship. He pursued his studies to the verge of starvation; his heated brain worked while his body shivered before a fireless stove, often covered with ice. His book, which placed him before his death, in 1854, among the greatest of German physicists, was coldly received by his colleagues in the College of Jesuits, at Cologne. On the contrary, Professor Henry's recognition was prompt and sympathetic, at home and abroad; at a single bound he came to the front, and there he always remained.

In 1832, Professor Henry removed to Princeton to fill the chair of Natural Philosophy in the College of New Jersey. Here he found sympathizing associates, congenial duties, and the opportunity for original research. One year earlier Faraday, already widely known by his chemical discoveries, appeared upon the field of experimental electricity, and immediately became the most conspicuous figure thereon, the cynosure of admiring eyes in every land. His discovery of induced currents, and of the evolution of electricity from magnets, marked a new era in the science of electricity, elucidating facts which had defied the ingenuity of Arago, Herschel, and Babbage, creating the science of magneto-electricity as the correlative of electro-magnetism, and justly claiming for its last-born the splendors and wonders of the Ruhmkorff coil, the Gramme machine, and the telephone. Henry supplemented the work of Faraday by his own discoveries of the *extra*-current in the primitive circuit, and of induced currents of higher orders in as many adjacent circuits. He also succeeded where Faraday had doubts about his own experiments; viz. in obtaining unequivocal indications of similar induction in the momentary passage of electricity of high tension; proving also the oscillating discharge of the Leyden jar. Numerous experiments were made on induction by thunder-clouds, and on atmospheric electricity in general, by means of tandem-kites and lightning-rods.

Nobili and Melloni had widened and deepened the foundations of thermotics, unveiling new and intimate analogies between radiant light and heat, and enriching physical cabinets with many novelties, especially the thermopile and the galvanometer. Henry took advantage of the new instruments for measuring the heat of different parts of the sun. Secchi, the late astronomer and meteorologist of the Collegio Romano, distinguished as the foster-brother of Victor Emmanuel, but more as the gifted expounder of solar physics, owed his first inspiration in science, in his youth (for he died in 1878, at the age of fifty-nine), to Henry, whom he assisted in these experiments. Doubtless, other young men, if they could be heard, would confess to an equal enthusiasm for science, caught from the same high example. But the multitudinous productions which issued in rapid succession from the prolific brain and pen of Secchi, without the adventitious reinforcement of imaginary cases, justify and demand the assertion that what Henry led others to do is second only in importance to what he did himself.

More than fifty years ago, a little book was published under the fascinating title of "Philosophy in Sport made Science in Earnest." Of the many ingenious, complex, and costly instruments of research,

has any one been richer in its revelations to science than the child's soap-bubble? But where the child saw only an evanescent display of colors, Newton read with mathematical clearness his celebrated theory of fits of easy transmission and reflection, and Young measured the constants of the undulations of light. To-day, the microscopic molar or molecular motions of the telephone-plate are translated into visible speech by the colors of a sympathetic film of liquid in the phoneidoscope. In 1844, Henry experimented with this ever ready minister to the delight and instruction of all ages, so beautiful but apparently so tender, and found that its cohesion and its contractile force were those of a giant if its own thinness were made the standard of measure. Thus was opened an avenue into the study of molecular action which Plateau has extended and embellished with the most varied and original experiments, not disheartened by the total loss of eyesight: finding by the way a beautiful experimental illustration of the cosmogony of La Place, and building architectural forms out of liquid films as if they had the cohesion of marble.

When, at the close of 1846, Professor Henry left the quiet walks of the Academy for a more public career in Washington, in obedience to the summons of the Regents of the Smithsonian Institution, though all applauded the wisdom of the choice, not a few regretted the sad interruption in his scientific life, already rich in performance and bright with the promise of more and perhaps greater discoveries. The sacrifice seemed to be too great to demand of science in a country where the taste and the mental qualifications, combined with the opportunity, for original research are rare. If Professor Henry had remained at Princeton, he would certainly have added other jewels to his crown: would it, however, have shone more brightly than it now shines? When posterity makes up its verdict on his claim to its gratitude and remembrance, his discoveries will not be counted, but weighed.

On the other hand, no friend of science can contemplate with complacency the possible alternatives if the Regents had come to a different choice, or if they had been defeated in their first selection. Literature or science; popular lectures or original research; the diffusion of old truth or the discovery of new truth; a national library, a national university, or a national museum, — each had warm and influential advocates. Professor Henry's plan of organization bears the date of December 8, 1847, and was adopted by the Regents on the 13th of December. It took its departure from the words of the founder, viz. *an establishment for the increase and diffusion of*

knowledge among men; and it emphasized every word of the pregnant sentence. Not science in its restricted sense, but knowledge was to be first increased, and then diffused world-wide, — by the endowment of research; by the publication and liberal distribution of contributions to knowledge, which may have little value in the market, but which are of transcendent importance to man's culture and civilization; by elaborate reports in special departments, in which the known would be separated from the unknown for the benefit of new explorers; by the translation of writings otherwise inaccessible to most students; by opening a highway along which the current literature and science of the day could easily pass from continent to continent, and reach their remotest corners. This sober and catholic scheme, in literal fulfilment of the will of Smithson, was less dazzling to the popular imagination, and enlisted a smaller numerical support, than rival propositions which were more on the level of the average understanding. Because these antagonistic plans narrowed the enjoyment of a benefaction, (itself absolutely unfettered,) to a small community, they secured a local influence which threatened to defeat the comprehensive views of the Secretary. These views, recommended by their reasonableness and indorsed by individuals, academies, and societies of science and learning, had a tower of strength in the high scientific reputation and the weight of character of the Secretary himself. Winning and persuasive in his manner, he was inflexible in his purpose.

Experience has proved the truth of that which was the contention at the time ; viz. that universities, libraries, museums, lectures, because they confer local benefits, will never lack endowments, whereas the Christian world had waited eighteen centuries for a large-minded and large-hearted benefactor, whose bequest was all knowledge, existing or to be discovered, and whose recipients were all nations of men. Slowly but steadily time has revealed the wisdom and foresight of the Secretary; individuals and communities, in increasing numbers, have felt the benefits of his administration; the government of the United States has known where to look for impartial advice on matters outside of its own knowledge, in times of prosperity and also in its darkest days; and now all opposition has died out; and, after a trial of thirty years, no one probably desires any thing better for the Smithsonian Institution than that the plan, so wisely conceived and so faithfully administered by the first Secretary, should continue the abiding rule for his successors.

Moreover, the plan of Professor Henry, cosmopolitan in its geo-

graphical embrace, did not sacrifice the interests of the unborn to those of the living. He would not allow the hopes of Smithson to be frustrated by lavishing upon a single generation what was intended for all time; or, what is worse, sacrificing both the present and the future upon the altar of an ambitious architecture. Examples abound, if experience is all which men need, of fatal shipwrecks on these alluring shores; of endowed churches, colleges, observatories, laboratories, libraries, which have nothing to show but a mass of masonry, lacking in the highest beauty of art, (fitness for its purpose,) however much it may please the eye, even if the merciless architect had left any thing for administration. The rigid rules of science, unqualified by good common sense, may work a disaster in matters of business. The consummate mathematician, La Place, omnipotent in the domain of physical astronomy, when appointed by Napoleon I. to a high office of state, attempted to carry the laws of the infinitesimal calculus into his administration, and failed. Not a few men of brilliant intellect, masters of thought and of the pen, have prided themselves on a childlike simplicity in the ways of the world. If Professor Henry had been one of these, much would have been forgiven to his honesty of purpose, to his love of truth, and to the success with which he had wooed her in her most secret recesses. Therefore, it is not the least of his triumphs that he did not, in imitation of an old astronomer, walk into a pitfall on this lower earth while gazing into the depths of space. He could roam with Emerson through the universe of thought, but the feet of both were firmly planted on the ground. Henry's judicious system of expenditures, so essential to the permanent prosperity of the Institution, put to shame the short-sightedness and the short-comings of many professed financiers; and exemplified, by anticipation, the magical products of the Holtz and Ladd induction machines, in which a trifling capital of well-invested electricity, the income of which is partly spent and partly saved, yields an ample return for the present, and by the law of compound interest secures still more brilliant results for the future.

When Professor Henry left Princeton, he knew, and his friends knew, that he must leave behind him the object of his highest ambition, viz. the undisturbed and the unostentatious study of the unfolding laws of the material universe. But he did not, and he could not, renounce the spirit of independent research which had made him what he was. As opportunity offered in the discharge of his official duties he manifested this spirit himself, and communicated it to others. His second report to the Board of Regents, for 1848, exhibits the promptness with which he had conceived, and begun to execute, the project

of covering the United States, and eventually the North American continent, with a net-work of meteorological stations, which, with the facilities of the telegraph, yet in its infancy, would prove a perennial blessing to commerce and agriculture; and, by consolidating the scattered efforts of eminent meteorologists (among whom Coffin, Espy, Loomis, and Guyot were conspicuous), throw some light on the law of storms and meteorology in general. In the Patent Office Report for 1857, he gave his views of the relations between meteorology and agriculture. In this and other ways, the Smithsonian Institution has been a hot-bed for starting and nursing new projects in their days of infancy and weakness. After they have outgrown its accommodations and proved their usefulness, they have been adopted by the general government and transplanted to a richer soil.

For many years Professor Henry has been a conspicuous figure, not merely in scientific circles, but in the full view of the public; his name and his co-operation have been in constant demand. He naturally gravitated to places of honor which were often places of additional labor. Men of leisure have no time to give to occasional calls upon their public spirit. The hard-workers must also do all the extra work. Professor Henry was no exception to this rule. To the day of his death, he filled positions of trust and responsibility, with duties sufficient to crush an effeminate man. But they seemed to rest lightly upon shoulders which sustained, beside, the weight of a great institution. His mind was ever in a state of prolonged tension; but it kept its balance under these distractions, as do the rings of Saturn amid the multitudinous disturbances of its satellites. Often he waited for the leisure which never came to him when he might write out for publication scientific communications which he had made from a brief. He was President of the American Association at its second meeting, in Cambridge, in 1849. He gave the usual address of the retiring President at the fourth meeting, in New Haven, but it was not printed. He was Vice-President of the National Academy of Sciences in 1866, succeeded Dr. Bache as President in 1868, and died in office.

The most responsible and the most onerous of the gratuitous services which he gave to science and the country were rendered in his capacity of member of the Light-House Board, of which he was for seven years the chairman. The substitution of lenses for mirrors began the revolution in light-houses; but lens or mirror, without the light, is no better than a steam-engine without steam. To conquer prejudice by experiment, and save millions to the country by exchanging sperm oil for lard oil, is not so brilliant a service as the discovery of a new law

of nature. But, more than any discovery, it makes science respected in high places, and enlists the sympathy of the unscientific community. There are times when sextants, chronometers, tables of the moon, and even light-houses, are of no avail, and an impenetrable veil of darkness shuts out the mariner from the lights of heaven and earth. But what is opaque to light may be pierced by sound. The experiments which have been made by Henry in this country and by Tyndall in England, in their official capacity, on the fog-penetrating power of the fog-horn, the fog-bell, the siren, the steam-whistle, and cannonading, have raised interesting questions in science, to which different answers have been given; but the facts remain, above controversy, to instruct governments in the best way of supplementing optical signals by acoustic signals. These last investigations of Professor Henry, to which, it is feared, he was a willing martyr, will always have a pathetic interest for those who knew and loved him.

It has been the aim of this notice to place in strong relief a few of the salient points in the intellectual life of Henry. Any statement in detail of the accumulations of his long life, in the way of experiment or deduction, must be very voluminous or very meagre. For he was not a concentrated specialist. His expanded thought swept the whole vast horizon of the physical sciences; not to speculate, but to discover. The severe discipline of science did not harden him against the fascinations of literature, poetry, and art.

It would be a delicate task, and premature, to attempt to assign to Henry his exact rank among those who have legislated for science in this and former centuries. There are laws of perspective in time as well as in space, whereby a small eminence seems to outclimb the distant Alps, and the present generation dwarfs apparently all its predecessors. Foreign countries and posterity will pronounce their irreversible verdict in this as in other cases. In his own country, and among his contemporaries, Mr. Henry was long and easily the acknowledged chief of experimental philosophers. If the earlier science of the country is passed in review, only a few names shine so brightly across the intervening years as to deserve any comparison with him who has recently departed. Winthrop and Rittenhouse in astronomy, Franklin in electricity, Rumford in thermotics, and Bowditch in mathematics, exhaust the catalogue of possible rivals. Of these, all but Winthrop were self-instructed, as was Henry, at least in what relates to their higher education. Of these, Franklin and Rumford, no less than Henry, were as remarkable in administration as in science; Franklin and Rumford from taste, and Henry from a sense of duty.

All three served their country well, — Franklin and Henry while living, and Rumford by his bequests. Winthrop, Rittenhouse, and Bowditch reached their exalted position by paths wholly untrodden by Henry. They cannot, therefore, be the standard for his measure. Rumford's mind was essentially practical, even in its science. He had more of the spirit of an inventor than a discoverer. In Henry's place he would have been more interested in pushing the telegraph to its final issue than in supplementing Faraday's laws of electro-dynamical induction. But in dealing with the heat of friction, Rumford displayed an experimental skill and a boldness of conception which have vindicated his claim to a high scientific position. The progress of recent discovery and the tendency of scientific speculation have promoted Rumford from the position which he long held, as leader of a forlorn hope, to the place of hero in the last act of the scientific drama. In this connection Henry's views on the correlation of the physical and organic forces may be recalled, which only lacked the fuller development and the wider publication which he finally gave to them, to have secured for him the first complete announcement of one of the grandest generalizations of modern science.

It might seem to be easy to institute a comparison between Franklin and Henry in reference to the value of their original scientific work, which was largely in the field of electricity. But a century has made great changes in the starting-point, the opportunities, and the resources of the discoverer. Franklin, with humble tools, had a virgin soil to cultivate. He had also the rare felicity, for which Newton also was envied, of living at a time when the scattered facts of a new science were waiting for a comprehensive generalization. If Franklin had made no experiments on the Leyden jar, or on the thunder-cloud, his theory of electricity, which has held its own to this day without any amendment (though its final doom is written upon it), would have secured for him a place second to no other among the worthies of science. Now the instruments of physical research are numerous and delicate; but useless unless the senses are educated to them. The literature of science is voluminous and in many languages. Success in scientific investigations demands now original thought, disciplined senses, scientific culture, and a well-chosen field, where the discoveries of other men will not be repeated. Both Franklin and Henry burned brightly in their allotted spheres, and in the future may differ only as one star differs from another star in glory.

The funeral services on May 16, 1878, proclaimed to the world that the republic had lost an illustrious citizen. There was no hollow

pageant of empty carriages of state, but the highest and best in the land felt a personal bereavement. A patriotic and devoted servant of the government was dead; a bright light in science had gone out; a noble man, born to attract and to sway, in whom science was illuminated by faith, and faith was enlightened by science, lived on earth no longer except by his example; a long life, crowded with beneficent services to truth and to man, was closed. Not less affecting were the memorial exercises of January 16, 1879, in the hall of the House of Representatives, before the assembled wisdom and grandeur of the nation. Science may be proud of this spontaneous tribute to her favored child, if she only remembers that it is character which makes intellect a blessing and not a scourge to mankind, and awakens genuine sympathy and admiration. Mr. Henry was not the favorite and ornament of a court, but the peer of the greatest and wisest in a free republic. The monument of Humboldt was not thought to be worthy of a place in sight of the King's palace in Berlin. That was a spot consecrated to princes of the blood and military heroes. Will any American think that any ground in this country is too sacred to contain a monument to Henry?

STEPHEN THAYER OLNEY.

Stephen Thayer Olney died at Providence, his native city, on the 27th of July, 1878, at the age of sixty-six, thus reducing to a small number the list of Associate Fellows in the botanical section. Colonel Olney was for most of his life actively engaged in business, for several years at Augusta, Georgia, and afterward in Providence. But he early became fond of Botany, published a Catalogue of Rhode Island Plants in the year 1844, and two critical papers on the Botany of the State a few years later. These appeared in the Proceedings of the Providence Franklin Society, over which institution he presided for many years, taking a leading part in the development of its scientific interests. He was a keen observer, made interesting contributions to his favorite science through his correspondence with the principal botanists of his day engaged in publication, formed a large and valuable herbarium and a choice botanical library, and, selecting for special investigation the very large and difficult genus *Carex*, he had become the leading critical authority in this department. He had planned an extensive work in illustration of this genus, had begun the distribution of accurately-named specimens and the preparation of costly figures, and had entered upon the characterization of new species, in the Pro-

ceedings of our own society, and elsewhere. But now ill health and sorrow arrested his work, and a cloud of mental infirmity overcast his last days. He was a man of fine appearance, full of energy, business talent, and public spirit, and of marked character. He was unmarried. He gave his botanical collections and library to the University of his native State, and bequeathed the principal part of the somewhat ample property which he had acquired to excellent charities, and for the promotion of the study of his favorite science in the State of Rhode Island. If his bequest for this purpose is carried into full effect, a very important foundation will be laid for the study of botany in this country, which should keep his name in perpetual remembrance. The name of Olney is borne by more than one species of plant of his own discovery, and by a remarkable genus, a Leguminous tree of Arizona, discovered by one of his former associates.

GEORGE B. WOOD.

THERE are but few names in the medical profession of this country more widely known than that of DR. GEORGE B. WOOD.

Holding as he did, for thirty-eight years, important professorships in the chief centre of medical learning on this continent, his influence upon hundreds of students of pharmacy and medicine must necessarily have been deeply felt and wide spread.

He was born at Greenwich, New Jersey, March 13, 1797, and educated at the University of Pennsylvania, receiving his degree in 1818.

In two years after graduation he began to teach chemistry, and in two years more was appointed Professor of that science in the Philadelphia College of Pharmacy. From this time onward he was engaged in the teaching of materia medica and of the theory and practice of medicine, until his appointment as Professor Emeritus in the University of Pennsylvauia, in 1860. With this event, however, his interest in medical education did not cease, for in 1865 Dr. Wood endowed an auxiliary Faculty of Medicine in the University of Pennsylvania for the teaching of certain sciences, which are usually somewhat thrust aside or neglected in the hurried three (or two) years of the usual American medical course.

Dr. Wood was the author of numerous and valuable works, chiefly relating to his profession, although a volume of historical and biographical papers was published in 1872.

His most voluminous and best-known works were the United States Dispensatory, written in conjunction with Dr. Franklin Bache, and

first published in 1843, a "Treatise on the Practice of Medicine," in 1847, and a "Treatise on Therapeutics and Pharmacology," in 1856. All of these went through several editions.

Of these, the first work is probably that in connection with which his name will be always remembered. Although only a part author, it is stated that he wrote fully two thirds of the book. A certain amount of familiarity with this volume and with its subject is necessary for an appreciation of the vast amount of labor and research which must have been bestowed upon it. Although at the present day the changes of commerce have made a part of the information contained therein unreliable or useless, and the chemical and therapeutic sciences must of course leave it behindhand in their rapid progress, yet there is hardly a subject connected even remotely with materia medica on which an amount of information commensurate with its importance cannot be found, and it must always remain, not only a monument to the fidelity and industry of the authors, but a fixed landmark of the most advanced position of the pharmaceutic sciences at the time of its publication.

The life of Professor Wood was a long and active one, and he was enabled to see the fruition of his own work, and enjoy the well-earned honors of the veteran in his profession.

FOREIGN HONORARY MEMBERS.

FRIEDRICH WILHELM RITSCHL.

Friedrich Wilhelm Ritschl died at Leipzig, November 9, 1876. He was born April 6, 1806, in Grossvargula, near Erfurt, attended school at Erfurt and Wittenberg, and entered the University of Leipzig as student of Law. He soon transferred himself to the department of Classical Philology, in which he ultimately became the first of living scholars. He finished his academic studies at Halle, where, in 1829, he began to lecture as *Privat-docent.* In 1832 he was made *Professor extraordinarius* at Halle, and in 1833 *Professor ordinarius* at Breslau. In 1839 he went to Bonn as Professor, and there he passed the most active period of his life as a teacher, from 1839 to 1865. Few, if any, American students of philology in Germany during that period failed to spend at least one term in Bonn under the instruction of Ritschl. No other German professor of his day could inspire his

audience with such enthusiasm as he. He could rivet the attention of a hundred young men as easily while he explained the metre of an Ode of Pindar, as when he discoursed on a poem of Simonides. His personal influence on his favorite pupils was almost unequalled, and it still survives as a most important element in the German scholarship of the present generation. In 1865, in consequence of an unfortunate personal difference in which a large number of the professors of Bonn were directly or indirectly involved, Ritschl felt compelled to resign his professorship. It was a sad day for the University of Bonn when its first scholar and its chief ornament withdrew; but the older University of Leipzig wisely improved the opportunity to recover its ancient glory in philology, which it had lost since the death of Gottfried Hermann in 1848. Ritschl was welcomed back to the university in which he had begun his academic studies, and the throng of two hundred pupils in his lecture-room soon showed the wisdom of the authorities of Leipzig in securing him. His health, however, which had never been strong, soon failed rapidly; but his mind and his energy remained firm in spite of bodily infirmities. He continued at his post of duty until the last, and lectured in the university even after he was so infirm that he was carried to his desk in a chair.

Ritschl's chief services to philology were his critical labors on the text of Plautus, of which he has been called the "restorer," and his investigation of the more ancient forms of the Latin language as a basis for the scientific study of Latin Grammar. But, like many German professors of the highest learning and the widest influence, he exerted himself chiefly in educating a new generation of scholars, and inspiring young men with his own high ideal of scholarship, in which he set them a noble example of conscientious thoroughness, profound learning, and untiring zeal.

KARL FREIHERR VON ROKITANSKI.

Karl Freiherr von Rokitanski, the world-renowned pathologist, was born at Königgratz, Bohemia, in 1804. He was educated first at Leitmeritz, then at Prague, and lastly at Vienna, whither he went in 1824 as a medical student. He graduated in 1828, having already become assistant to Johann Wagner, Professor of Pathology. On the death of Wagner, in 1832, Rokitanski was made Professor, and was appointed Prosector at the Vienna General Hospital. Here his capacity for work proved almost incredible, a thousand autopsies a year being the usual number he averaged for scores of years.

As a lecturer his voice was feeble, his language provincial, and his manner indifferent. Yet, such was his scientific energy, and so valuable were his teachings, that students over-crowded the lecture-room and filled the college yard in their zeal to listen to him. The Vienna School owes its revival and present ascendency to him more than to any other individual. Though he propounded dogmas which severe criticism and further investigations led him to modify, yet under his leadership the science of medicine made immense progress. Even therapeutics was advanced by his labors, in spite of the taunts of medical nihilism unscrupulously thrown upon him and his followers.

In 1849 he was appointed Dean of the Medical Faculty, and in 1850 Rector of the University at Vienna. He was also made President of the Academy of Sciences, and of the Medical Society of Vienna. After thus attaining almost every academic or scientific honor possible, attested by unnumbered diplomas and decorations, and after exercising in public and private life unbounded influence on medical and general education, he died, universally lamented, July 23, 1878.

Since the last Report, the Academy has received an accession of twenty-three new members, as follows: sixteen Fellows, J. B. Ames, W. S. Appleton, Edward Atkinson, W. E. Byerly, James F. Clarke, F. W. Draper, C. F. Folsom, J. C. Gray, Jr., Alfred Hosmer, E. D. Leavitt, Jr., H. C. Lodge, J. P. Reynolds, R. H. Richards, H. H. Richardson, J. S. Ropes, and C. S. Sargent; one Associate Fellow, Asaph Hall; six Foreign Honorary Members, J. G. Agardh in place of Elias Fries, Thomas Carlyle in place of Louis Adolphe Thiers, F. C. Donders in place of Karl Rokitanski, F. M. de Lesseps in place of Victor Regnault, H. A. J. Munro in place of Paul Frederick Sclopis di Salerano, and John Ruskin at large. On the other hand, by removal from the State or by resignation, the following members of the Academy have abandoned their Fellowships: A. S. Packard, Jr., and J. K. Paine. The list of the Academy, corrected to the date of this Report, is hereto added. It includes 192 Fellows, 96 Associate Fellows, and 72 Honorary Members.

LIST

OF THE FELLOWS AND FOREIGN HONORARY MEMBERS.

FELLOWS. — 192.

(Number limited to two hundred.)

Class I. — *Mathematical and Physical Sciences.* — 60.

Section I. — 7.

Mathematics.

W. E. Byerly,	Cambridge.
Benjamin A. Gould,	Cambridge.
Gustavus Hay,	Boston.
Benjamin Peirce,	Cambridge.
James M. Peirce,	Cambridge.
John D. Runkle,	Boston.
Edwin P. Seaver,	Boston.

Section II. — 10.

Practical Astronomy and Geodesy.

J. Ingersoll Bowditch,	Boston.
Alvan Clark,	Cambridgeport.
George Clark,	Cambridgeport.
Henry Mitchell,	Roxbury.
Robert Treat Paine,	Boston.
E. C. Pickering,	Cambridge.
William A. Rogers,	Cambridge.
Arthur Searle,	Cambridge.
L. Trouvelot,	Cambridge.
Henry L. Whiting,	Boston.

Section III. — 28.

Physics and Chemistry.

John Bacon,	Boston.
A. Graham Bell,	Boston.
John H. Blake,	Boston.
Thos. Edwards Clark,	Williamstown.
W. J. Clark,	Amherst.
Josiah P. Cooke, Jr.,	Cambridge.
James M. Crafts,	Boston.
Charles R. Cross,	Boston.
William P. Dexter,	Roxbury.
Amos E. Dolbear,	Medford.
Charles W. Eliot,	Cambridge.
Moses G. Farmer,	Newport.
Wolcott Gibbs,	Boston.
Augustus A. Hayes,	Brookline.
Henry B. Hill,	Cambridge.
Eben N. Horsford,	Cambridge.
T. Sterry Hunt,	Boston.
Charles L. Jackson,	Cambridge.
Joseph Lovering,	Cambridge.
William R. Nichols,	Boston.
John M. Ordway,	Boston.
Robert H. Richards,	Boston.
Edward S. Ritchie,	Boston.
S. P. Sharples,	Cambridge.
Frank H. Storer,	Jamaica Plain.
John Trowbridge,	Cambridge.
Cyrus M. Warren,	Brookline.
Charles H. Wing,	Boston.

Section IV. — 15.

Technology and Engineering.

G. R. Baldwin,	Woburn.
John M. Batchelder,	Cambridge.
C. O. Boutelle,	Washington.
Henry L. Eustis,	Cambridge.
James B. Francis,	Lowell.
John B. Henck,	Boston.
E. D. Leavitt, Jr.,	Cambridgeport.
William R. Lee,	Roxbury.
Hiram F. Mills,	Lawrence.
Alfred P. Rockwell,	Boston.
Stephen P. Ruggles,	Boston.
Charles S. Storrow,	Boston.
William R. Ware,	Boston.
William Watson,	Boston.
Morrill Wyman,	Cambridge.

Class II. — *Natural and Physiological Sciences.* — 67.

Section I. — 9.

Geology, Mineralogy, and Physics of the Globe.

Thomas T. Bouvé,	Boston.
William T. Brigham,	Boston.
Algernon Coolidge,	Boston.
John L. Hayes,	Cambridge.
Charles T. Jackson,	Boston.
Jules Marcou,	Cambridge.
William B. Rogers,	Boston.
Nathaniel S. Shaler,	Cambridge.
Charles U. Shepard,	Amherst.

Section II. — 11.

Botany.

George B. Emerson,	Boston.
William G. Farlow,	Boston.
George L. Goodale,	Cambridge.
Asa Gray,	Cambridge.
H. H. Hunnewell,	Wellesley.
Thomas P. James,	Cambridge.
John A. Lowell,	Boston.
C. S. Sargent,	Brookline.
Chas. J. Sprague,	Boston.
Edward Tuckerman,	Amherst.
Sereno Watson,	Cambridge.

Section III. — 24.

Zoölogy and Physiology.

Alex. E. R. Agassiz,	Cambridge.
J. A. Allen,	Cambridge.
Robert Amory,	Brookline.
Nath. E. Atwood,	Provincetown.
James M. Barnard,	Boston.
Henry P. Bowditch,	Boston.
Thomas M. Brewer,	Boston.
Edward Burgess,	Boston.
Samuel Cabot,	Boston.
John Dean,	Waltham.
Hermann A. Hagen,	Cambridge.
C. E. Hamlin,	Cambridge.
Alpheus Hyatt,	Cambridge.
Wm. James,	Cambridge.
Samuel Kneeland,	Boston.
Theodore Lyman,	Boston.
Edward S. Morse,	Salem.
L. F. Pourtales,	Cambridge.
Frederic W. Putnam,	Cambridge.
James J. Putnam,	Boston.
Samuel H. Scudder,	Cambridge.
D. Humphreys Storer,	Boston.
Henry Wheatland,	Salem.
James C. White,	Boston.

Section IV. — 23.

Medicine and Surgery.

Samuel L. Abbot,	Boston.
Henry J. Bigelow,	Boston.
Henry I. Bowditch,	Boston.
Benjamin E. Cotting,	Roxbury.
F. W. Draper,	Boston.
Thomas Dwight,	Boston.
Robert T. Edes,	Roxbury.
Calvin Ellis,	Boston.
C. F. Folsom,	Boston.
Richard M. Hodges,	Boston.
Oliver W. Holmes,	Boston.
R. W. Hooper,	Boston.
Alfred Hosmer,	Watertown.
Edward Jarvis,	Dorchester.
Francis Minot,	Boston.
Edward Reynolds,	Boston.
J. P. Reynolds,	Boston.
George C. Shattuck,	Boston.
Horatio R. Storer,	Boston.
J. Baxter Upham,	Boston.
Charles E. Ware,	Boston.
John C. Warren,	Boston.
Henry W. Williams,	Boston.

CLASS III. — *Moral and Political Sciences.* — 65.

SECTION I. — 17.

Philosophy and Jurisprudence.

J. B. Ames,	Cambridge.
C. S. Bradley,	Cambridge.
Phillips Brooks,	Boston.
James F. Clarke,	Jamaica Pl.
Richard H. Dana, Jr.,	Boston.
C. C. Everett,	Cambridge.
John Fiske,	Cambridge.
Horace Gray,	Boston.
J. C. Gray, Jr.,	Boston.
L. P. Hicock,	Northampton.
O. W. Holmes, Jr.,	Boston.
Mark Hopkins,	Williamstown.
C. C. Langdell,	Cambridge.
John Lowell,	Boston.
Henry W. Paine,	Cambridge.
Theophilus Parsons,	Cambridge.
J. B. Thayer,	Cambridge.

SECTION II. — 15.

Philology and Archæology.

Ezra Abbot,	Cambridge.
W. S. Appleton,	Boston.
William P. Atkinson,	Boston.
H. G. Denny,	Boston.
Epes S. Dixwell,	Cambridge.
William Everett,	Cambridge.
William W. Goodwin,	Cambridge.
Ephraim W. Gurney,	Cambridge.
Bennett H. Nash,	Boston.
Chandler Robbins,	Boston.
John L. Sibley,	Cambridge.
E. A. Sophocles,	Cambridge.
John W. White,	Cambridge.
Justin Winsor,	Cambridge.
Edward J. Young,	Cambridge.

SECTION III. — 18.

Political Economy and History.

Chas. F. Adams, Jr.,	Quincy.
Henry Adams,	Boston.
Edward Atkinson,	Boston.
Erastus B. Bigelow,	Boston.
Charles Deane,	Cambridge.
Charles F. Dunbar,	Cambridge.
Samuel Eliot,	Boston.
George E. Ellis,	Boston.
E. L. Godkin,	Cambridge.
William Gray,	Boston.
Edward Everett Hale,	Boston.
H. C. Lodge,	Boston.
Francis Parkman,	Brookline.
A. P. Peabody,	Cambridge.
J. S. Ropes,	Boston.
Nathaniel Thayer,	Boston.
Henry W. Torrey,	Cambridge.
Robert C. Winthrop,	Boston.

SECTION IV. — 15.

Literature and the Fine Arts.

Charles F. Adams,	Boston.
William T. Andrews,	Boston.
George S. Boutwell,	Groton.
J. Elliot Cabot,	Brookline.
Francis J. Child,	Cambridge.
Ralph Waldo Emerson,	Concord.
John C. Gray,	Cambridge.
Henry W. Longfellow,	Cambridge.
Charles G. Loring,	Boston.
James Russell Lowell,	Cambridge.
Charles Eliot Norton,	Cambridge.
Thomas W. Parsons,	Wayland.
Charles C. Perkins,	Boston.
H. H. Richardson,	Brookline.
John G. Whittier,	Amesbury.

ASSOCIATE FELLOWS. — 96.

(Number limited to one hundred.)

CLASS I. — *Mathematical and Physical Sciences.* — 38.

SECTION I. — 8.

Mathematics.

Charles Avery,	Clinton, N.Y.
E. B. Elliott,	Washington, D.C.
William Ferrel,	Washington, D.C.
Thomas Hill,	Portland, Me.
Simon Newcomb,	Washington, D.C.
H. A. Newton,	New Haven, Conn.
James E. Oliver,	Ithaca, N.Y.
T. H. Safford,	Williamstown, Mass.

SECTION II. — 12.

Practical Astronomy and Geodesy.

S. Alexander,	Princeton, N.J.
W.H.C. Bartlett,	West Point, N.Y.
J. H. C. Coffin,	Washington, D.C.
Wm. H. Emory,	Washington, D.C.
Asaph Hall,	Washington, D.C.
J. E. Hilgard,	Washington, D.C.
George W. Hill,	Nyack, N.Y.
Elias Loomis,	New Haven, Conn.
Maria Mitchell,	Poughkeepsie, N.Y.
C. H. F. Peters,	Clinton, N.Y.
George M. Searle,	New York.
Chas. A. Young,	Princeton, N.J.

SECTION III. — 11.

Physics and Chemistry.

F. A. P. Barnard,	New York.
John W. Draper,	New York.
S. W. Johnson,	New Haven, Conn.
John Le Conte,	San Francisco, Cal.
A. M. Mayer,	Hoboken, N.J.
W. A. Norton,	New Haven, Conn.
Ogden N. Rood,	New York.
H. A. Rowland,	Baltimore.
L.M. Rutherfurd,	New York.
Benj. Silliman,	New Haven, Conn.
J. L. Smith,	Louisville, Ky.

SECTION IV. — 7.

Technology and Engineering.

Henry L. Abbot,	New York.
R. Delafield,	Washington, D.C.
A.A. Humphreys,	Washington, D.C.
John Rodgers,	Washington, D.C.
Wm. Sellers,	Philadelphia.
George Talcott,	Albany, N.Y.
W.P. Trowbridge,	New Haven, Conn.

CLASS II. — *Natural and Physiological Sciences.* — 27.

SECTION I. — 14.

Geology, Mineralogy, and Physics of the Globe.

George J. Brush,	New Haven, Conn.
James D. Dana,	New Haven, Conn.
J. W. Dawson,	Montreal, Canada.
Edward Desor,	Neufchâtel, Switz.
J. C. Fremont,	New York.
F. A. Genth,	Philadelphia.
Arnold Guyot,	Princeton, N.J.
James Hall,	Albany, N.Y.
F. S. Holmes,	Charleston, S.C.
Joseph Leconte,	San Francisco.
J. Peter Lesley,	Philadelphia.
R. Pumpelly,	Owego, N.Y.
Wm. T. Roepper,	Bethlehem, Pa.
Geo. C. Swallow,	Columbia, Mo.

SECTION II. — 3.

Botany.

A. W. Chapman, Apalachicola, Fla.
G. Engelmann, St. Louis, Mo.
Leo Lesquereux, Columbus, Ohio.
J. L. LeConte, Philadelphia.
Joseph Leidy, Philadelphia.
O. C. Marsh, New Haven, Conn.
S. Weir Mitchell, Philadelphia.
St. Julien Ravenel, Charleston, S.C.

SECTION III. — 8.

Zoölogy and Physiology.

S. F. Baird, Washington, D.C.
C. E. Brown-Séquard, London.
J. C. Dalton, New York.

SECTION IV. — 2.

Medicine and Surgery.

W. A. Hammond, New York.
Isaac Hays, Philadelphia.

CLASS III. — *Moral and Political Sciences.* — 31.

SECTION I. — 8.

Philosophy and Jurisprudence.

D. R. Goodwin, Philadelphia.
R. G. Hazard, Peacedale, R.I.
Nathaniel Holmes, St. Louis, Mo.
James McCosh, Princeton.
Charles S. Peirce, New York.
Noah Porter, New Haven, Conn.
Isaac Ray, Philadelphia.
Jeremiah Smith, Dover, N.H.

SECTION II. — 11.

Philology and Archæology.

A. N. Arnold, Hamilton, N.Y.
D. C. Gilman, Baltimore.
S. S. Haldeman, Columbia, Pa.
A. C. Kendrick, Rochester, N.Y.
Geo. P. Marsh, Rome.
L. H. Morgan, Rochester, N.Y.
A. S. Packard, Brunswick, Me.
E. E. Salisbury, New Haven, Conn.
A. D. White, Ithaca, N.Y.
W. D. Whitney, New Haven, Conn.
T. D. Woolsey, New Haven, Conn.

SECTION III. — 8.

Political Economy and History.

S. G. Arnold, Newport, R.I.
Geo. Bancroft, Washington.
S. G. Brown, Clinton, N.Y.
Henry C. Carey, Philadelphia.
J. L. Diman, Providence, R.I.
Henry C. Lea, Philadelphia.
Barnas Sears, Scranton, Va.
J. H. Trumbull, Hartford.

SECTION IV. — 4.

Literature and the Fine Arts.

James B. Angell, Ann Arbor, Mich.
F. E. Church, New York.
R. S. Greenough, Florence.
Wm. W. Story, Rome

FOREIGN HONORARY MEMBERS.—72.

(Appointed as vacancies occur.)

CLASS I.—*Mathematical and Physical Sciences.*—25.

SECTION I.—7.

Mathematics.

John C. Adams,	Cambridge.
Sir George B. Airy,	Greenwich.
Brioschi,	Milan.
Arthur Cayley,	Cambridge.
Chasles,	Paris.
Liouville,	Paris.
J. J. Sylvester,	Baltimore.

SECTION II.—5.

Practical Astronomy and Geodesy.

Döllen,	Pulkowa.
H. A. E. A. Faye,	Paris.
Peters,	Altona.
Otto Struve,	Pulkowa.
Emile Plantamour,	Geneva.

SECTION III.—10.

Physics and Chemistry.

R. Bunsen,	Heidelberg.
E. Chevreul,	Paris.
J. Dumas,	Paris.
H. Helmholtz,	Berlin.
A. W. Hofmann,	Berlin.
G. Kirchhoff,	Berlin.
J. C. Maxwell,	Cambridge.
Balfour Stewart,	Manchester
G. G. Stokes,	Cambridge.
F. Wöhler,	Göttingen.

SECTION IV.—2.

Technology and Engineering.

R. Clausius,	Bonn.
F. M. de Lesseps,	Paris.
Sir Wm. Thomson,	Glasgow.

CLASS II.—*Natural and Physiological Sciences.*—25.

SECTION I.—7.

Geology, Mineralogy, and Physics of the Globe.

Barrande,	Prague.
Charles Darwin,	Beckenham.
James Prescott Joule,	Manchester.
W. H. Miller,	Cambridge.
C. F. Rammelsberg,	Berlin.
A. C. Ramsay,	London.
Sir Edward Sabine,	London.

SECTION II.—7.

Botany.

J. G. Agardh,	Lund.
George Bentham,	London.
Decaisne,	Paris.
Alphonse de Candolle,	Geneva.
Oswald Heer,	Zurich.
Joseph Dalton Hooker,	London.
Nägeli,	Munich.

SECTION III. — 8.

Zoölogy and Physiology.

T. L. W. Bischoff,	Munich.
Milne-Edwards,	Paris.
Albrecht Kölliker,	Würzburg.
Rudolph Leuckart,	Leipzig.
Richard Owen,	London.
C. Th. Von Siebold,	Munich.
J. J. S. Steenstrup,	Copenhagen
Valentin,	Berne.

SECTION IV. — 3.

Medicine and Surgery.

Sir James Paget,	London.
Virchow,	Berlin.
F. C. Donders,	Utrecht.

CLASS III. — *Moral and Political Sciences.* — 22.

SECTION I. — 3.

Philosophy and Jurisprudence.

T. C. Bluntschli,	Heidelberg.
Sir Henry Sumner Maine,	London.
James Martineau,	London.

SECTION II. — 6.

Philology and Archæology.

Pascual de Gayangos,	Madrid.
Benjamin Jowett,	Oxford.
Lepsius,	Berlin.
Max Müller,	Oxford.
H. A. J. Munro,	Cambridge.
Sir H. C. Rawlinson,	London.

SECTION III. — 9.

Political Economy and History.

Thomas Carlyle,	London.
Ernst Curtius,	Berlin.
W. Ewart Gladstone,	London.
Charles Merivale,	Oxford.
F. A. A. Mignet,	Paris.
Mommsen,	Berlin.
Mark Pattison,	Oxford.
Von Ranke,	Berlin.
A. P. Stanley,	London.

SECTION IV. — 4.

Literature and the Fine Arts.

Gérôme,	Paris.
John Ruskin,	Coniston.
Alfred Tennyson,	Isle of Wight.
Viollet-Le-Duc,	Paris.

INDEX.

D.

E.

F.

R.

S.

T.

University Press: John Wilson & Son, Cambridge.